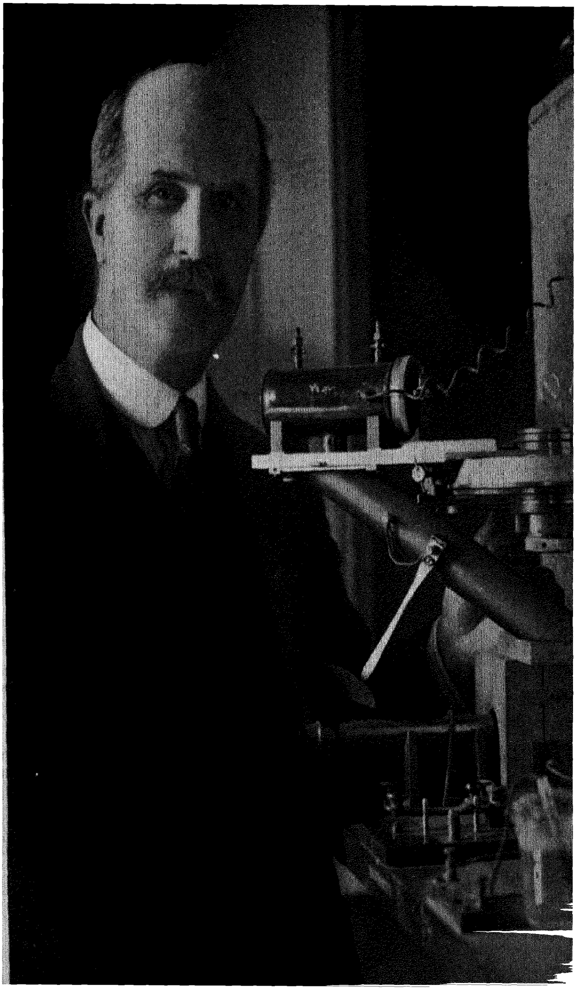

SIR WILLIAM BRAGG AND HIS X-RAY SPECTROSCOPE

Sir William Bragg, along with his son, has done the pioneer work in obtaining X-ra spectra of crystals by means of which their structure has been determined. S William Bragg is standing beside his X-ray spectrometer with which he has done h great work.

ELECTRICAL CONCEPTIONS OF TO-DAY

A LUCID EXPLANATION OF MANY OF THE LATEST THEORIES CONCERNING ATOMS, ELECTRONS & OTHER MATTERS RELATING TO ELECTRICITY

BY

CHARLES R. GIBSON. LL.D., F.R.S.E.

"SCIENTIFIC IDEAS OF TO-DAY" "WHAT IS ELECTRICITY?"
"THE ROMANCE OF SCIENTIFIC DISCOVERY" &c. &c.

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ELECTRICAL CONCEPTIONS OF TO-DAY

CHAPTER I

ALL IS ELECTRICITY

On one occasion, twenty years ago, the author was amusing a small boy by charging him with electricity from an electric machine, and drawing sparks from him. The little fellow asked if there was any electricity in him, and his amusement was great when he was informed that he was made of electricity. Doubtless, his idea was that electricity was composed of sparks.

It is difficult to realise that every existing thing is made entirely of positive and negative electricities, but it is none the less true. And although we cannot discover what electricity is, there seems little doubt that it must be some entanglement of the ether of space.

Commencing with solid matter, we find that it consists of infinitesimally small particles or *molecules*, that these are composed of atoms, and that these again are composed of positive and negative electricities, these probably being com-

posed of the ether of space. We may form a picture of the Creation in the following manner. In the beginning there was nothing but the great limitless ocean of ether, which we are justified in describing as "mysterious," for nothing can be discovered concerning its nature, though its properties have been studied as far as that is possible with our present means; the ether itself avoids our grasp. We are on the surface of a great planet, which is flying through the ether at a speed of one thousand miles per minute, and yet we can carry with us that flimsy blanket of gases which we call the atmosphere. If the ether offered any appreciable resistance to our headlong flight, we should certainly lose this envelope of gases. Matter can pass through the ether without any appreciable resistance; it is not disturbed by matter.

I hope none of us doubt the existence of the ether of space, for Sir Isaac Newton has said, speaking of the idea of empty space: "It is so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it."

Some people have supposed that Einstein's theory of Relativity dispenses with the ether, but here is what Einstein said: "According to the general theory of Relativity, space without ether is unthinkable, for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time. . . . But this ether may not be thought of

as endowed with the characteristic of ponderable matter."

Ancient philosophers invented ethers in which the planets could swim ; it was too ridiculous to think of heavy bodies being supported by empty space. How can we picture the Moon tethered to the Earth, without the existence of a connecting medium such as the ether. Otherwise we could not drag the Moon with us in our monthly waltz and annual race around the Sun. When we lift a stone from the Earth, what guides it back but the ether ? We do not know what gravitation is, but we believe it to exist in the ether. Are we not satisfied that light is a series of successive waves in the ether ? How could we picture the transmission of our wireless messages, except with the ether as the medium of communication ? When we think of electric and magnetic fields, wherein do they exist, but in the ether ? The mathematician might be willing to dispense with the necessity of the ether, but most of us wish to visualise things, and to that end the ether is a necessity.

Setting out with nothing but the ether, which is "without form and void," we may imagine infinitesimal parts of this boundless ocean becoming differentiated from the main body in some way. We might picture the formation of vortex rings, such as are seen in smoke rings. These are, of course, merely vortices in the ocean of air, coloured by smoke.

When producing smoke rings by means of a

cardboard box, an interesting experiment may be made without the presence of smoke. Chemicals produce the smoke, while a sharp blow on the flexible back of the box sends smoke through a circular hole in the front of the box. It is convenient to use the smoke in arranging the experiment, which is to blow out the flame of a candle at some distance from the smoke box, and this by shooting a vortex ring of air at the flame. The required positions of the smoke box and the distant candle can be arranged by shooting smoke rings till the target is struck. Then the smoke may be removed and the candle-flame may be blown out by shooting an invisible air ring or vortex. So long as the air vortex is in motion it is differentiated from the ocean of air, and in similar fashion we may picture individual vortices formed in the ether of space. The energy of the air vortex is soon dissipated by friction with the surrounding air, and the smoke ring ceases to exist, but the ether is frictionless; so the ether vortex persists. The Vortex gives an imaginary picture of what we call a particle of negative electricity or an *electron.*

In thinking of electrons as part of the constitution of the atom of matter, and remembering that like electricities repel one another, it is needless to say that an atom of matter cannot be composed entirely of electrons—there must be a counterbalance of positive electricity, otherwise the electrons would fly apart from one another.

Lest any reader is not conversant with the

idea of the two different electricities, we might inquire how our knowledge of these has come about.

We know that at least 600 years B.C. the ancient philosophers commenced man's knowledge of electricity by rubbing pieces of amber, and causing them to attract light bodies. Then followed the discovery (A.D. 1600) that glass, sulphur, resin, etc., would act in the same manner when rubbed. At a later date, simple glass cylinder and glass-plate machines were made to do the rubbing on a larger scale, and by means of these machines bodies could be charged with electricity, and electrical science progressed thereby. But how do we know that there are two kinds of electricity?

If we charge two pith-balls, or other light objects, by touching them with an electrified glass rod, the balls, being similarly electrified, will repel one another. Like electricities repel. If we charge the balls by touching them with an electrified vulcanite rod, the balls will again be similarly electrified, though not necessarily with the same kind of electricity as before, but again they will exhibit repulsion. If we charge one ball by the glass rod, and the other ball by the vulcanite rod, the balls will attract one another. It is quite evident that they are charged with different electricities, otherwise they would repel one another. Unlike electricities attract one another. At first the electricity from the glass rod was called *vitreous electricity*, and that of the other rod, which was at that time resin, was called *resinous*

electricity. Lord Kelvin thought it a pity that these names were abandoned for *positive* and *negative* electricities, which names are not descriptive. We shall see, as we go along, that our knowledge of negative electricity has progressed much further than our knowledge of positive electricity. Indeed, it is difficult to suggest any helpful analogy of what positive electricity may be, but we feel sure that it is also some entanglement of the ether of space.

It has been suggested that the negative particle (electron) may be analogous to a bubble—a space from which the ether has been removed by a vortex motion, and that the positive particle may be crammed full of ether possibly in a vortex.

Benjamin Franklin—in his one-fluid theory—supposed one kind of electricity (we say negative), and that the other something in nature was matter itself. All we can say is that it is the positive particle in which the mass of the atom resides, whereas the electron has practically no weight. Electrons by themselves are not matter; they go to make matter.

We cannot say that we know what negative electricity is; we only conjecture that it may be some form of motion in the ether, and even if we could discover what kind of motion it is, and even if we could prove definitely that negative electricity is composed of the ether, we would have made but little progress, as we have no idea as to what the ether is.

Up till the last year of the eighteenth century

man's knowledge of electricity consisted in dealing with charges of electricity produced by frictional machines. The electric current was not discovered till the year 1800; had it been one year later it would have been a nineteenth-century discovery.

It is well known how the electric current was discovered. Galvani, a Professor of Anatomy in Italy, made what might seem an almost unimportant discovery concerning a frog's legs. Describing his discovery, Galvani says: "I had dissected and prepared a frog, and laid it on a table, on which, at some distance from the frog, was an electric machine. It happened by chance that one of my assistants touched the inner crural nerve of the frog with the point of a scalpel, whereupon at once the muscles of the limbs were violently convulsed."

"Another, who used to help me in electrical experiments, thought he had noticed that at this instant a spark was drawn from the conductor of the machine, but when he drew my attention to this, I greatly desired to try it for myself, and discover its hidden principle. So I, too, touched one or other of the crural nerves at the same time that one of those present drew a spark, and the same phenomenon was repeated as before."

Galvani then desired to try the effect of lightning and also of atmospheric electricity in calm weather. He fastened a brass hook in the spinal marrow of a frog's legs, and hung this on an iron lattice which was in his garden. He found the legs twitched even in the absence of a thunder-

storm. He suggested this was due to changes of electric conditions in the atmosphere. He thought that electricity from the atmosphere had slowly entered the animal and accumulated in it, and that it was suddenly discharged when the brass hook came in contact with the iron lattice.

Another Italian, Volta, a Professor of Natural Philosophy, could not accept this idea of the electricity being inherent in the animal, and he suggested that the electricity resided in the two dissimilar metals, and that there was a discharge between them when they were placed in contact. Volta's own words are: "The metals used in the experiments, being applied to the moist bodies of animals can, by themselves, excite and dislodge the electric fluid from its state of rest, so that the organs of the animal act only passively."

The dispute regarding the frog was not settled in Galvani's time, for it was in the year after his death that Volta made the important discovery which led to the invention of the electric cell or battery.

In the spring of 1800, Volta made a pile of metal discs of dissimilar metals, zinc and copper. Instead of using the moist flesh of a frog, he used pieces of cloth moistened in acidulated water. He built up a pile with a disc of copper upon a disc of zinc, and then a moist cloth which separated these from the next couple, and he found that there was a flow of electricity through a wire joining the uppermost copper and the lowest zinc. This was the discovery of the electric current and the

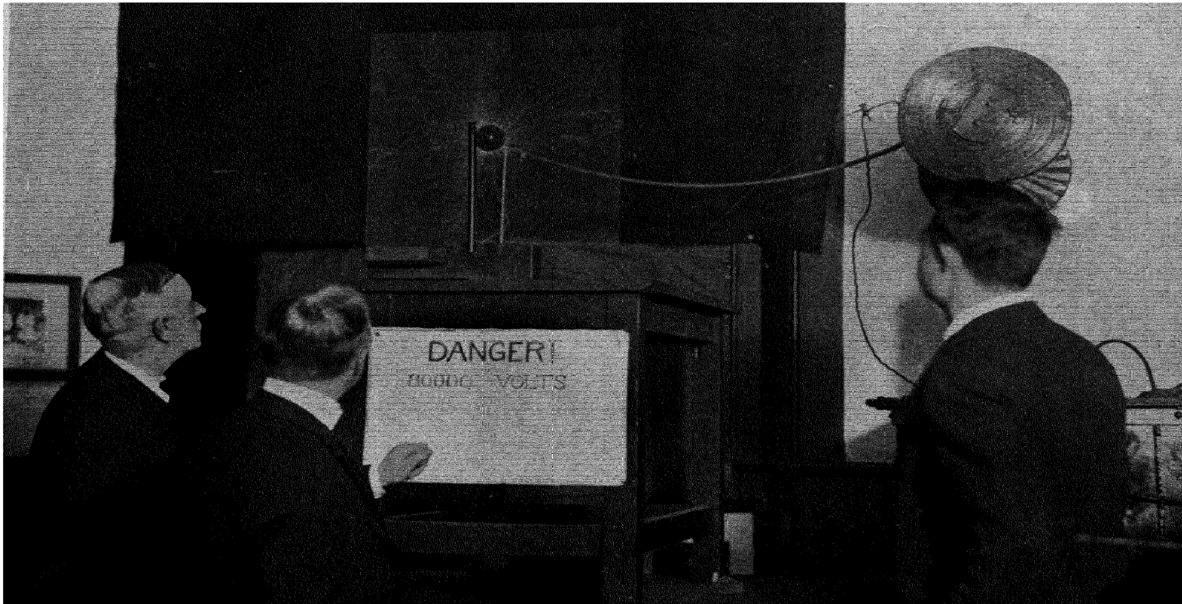


Photo *Sport and General*

A HIGH VOLTAGE

The electric discharge shown in the photograph is produced by a pressure of 80,000 volts. We commenced with a pressure of a few volts produced by Volta's pile. A demonstration of this discharge was given at King's College, London, at an exhibition in aid of the King Edward's Hospital Fund for London.

invention of the electric battery. Volta also arranged each couple of metals in a vessel of acidulated water.

When experimenting with the first Voltaic pile made, in Great Britain, from a description of the apparatus, it was discovered by Nicholson and Carlisle that the electric current had a chemical effect. They observed that when the two wires of the pile were placed in water there were bells of gas rising from the end of one of the wires, while the end of the other wire became corroded. In order to prevent this corrosion they attached pieces of platinum to the ends of the wire, whereupon gas was evolved at the ends of both wires. When these gases were collected and tested, they were found to be oxygen and hydrogen, of which elements the water was known to be composed, so it was evident that the water was being decomposed. A few years later (1807) Sir Humphry Davy found that solids might also be decomposed by the electric current, and he succeeded in isolating potassium from its compound; the element itself having been unknown until then.

Some years later (1820) Hans Christian Oersted (Denmark) discovered the connection between electricity and magnetism. He had often sought to find some connection but failed, until one day, when he was lecturing to his students, it occurred to him to try the effect of placing a magnetic compass needle in the vicinity of a wire through which an electric current was flowing. He hap-

pened to place the needle at right angles to the wire and nothing happened ; there was apparently no effect, but after the lecture it occurred to him to place the needle in the same plane as the wire, whereupon it swung round and took up a position at right angles to the wire. During the lecture he had placed it in this position, and, of course, nothing happened.

Another discovery concerning the electric current was made in 1822, when Professor Seebeck (Germany) found that an electric current could be generated by heating the junction of two metals. The metals he found best suited were Bismuth and Antimony, and when such a couple was heated at the junction there was a flow of electricity through a wire joining the free ends of the metals. Thermo-electric currents have been produced by using a battery of metallic couples such as described, but it is found to be an expensive method. The thermo-electric couple has been used to great advantage for the reading of very high and very low temperatures. The couple is placed in the source of heat, and the amount of current generated is dependent upon the temperature.

Faraday's great discovery that an electric current could be generated by mechanical means was made in 1831. He found that when a coil of wire is moved in a magnetic field an electric current is produced in the wire. This phenomenon is the basis of the dynamo, in which a coil of wire is revolved between the poles of a powerful

electro-magnet. It need scarcely be pointed out that this discovery made by Faraday in 1831, and which is based on Oersted's earlier discovery, forms the basis of all electrical engineering. However, our present interest lies in the inner meanings of the various phenomena, and before considering the experimental work by which we have gained our knowledge, it will be of interest to consider what our present knowledge is.

CHAPTER II

OUR PRESENT KNOWLEDGE

As we are going to consider the experimental side, it will be well to realise the great value of experiment in the progress of scientific knowledge.

Living in the twentieth century, it is difficult to realise how, in ancient times, and right through the Middle Ages, people determined to have nothing to do with experiment, preferring to depend upon the philosophy of Aristotle.

It is difficult for us to realise the condition of thought in the early days of Oxford when students who dared to dispute the writings of Aristotle were made to pay a fine on each occasion of disagreement.

It is worth while being reminded of the well-known experiment made by Galileo in Italy when he challenged one of Aristotle's dictums; the condition of thought in this country was very similar; Aristotle's philosophy was supreme.

In his student days, Galileo had been nicknamed "The Wrangler," because he had dared to question the truth of some of Aristotle's writings. Professors and students in the University of Pisa were horrified when the youthful professor, Galileo, declared that Aristotle was wrong in

saying that a heavy weight would fall with greater speed than a lighter weight. It was very bold of Galileo to propose an experiment from the Leaning Tower of Pisa, but the professors and students had every confidence that Aristotle was right. It is interesting to read what they said when they saw the two unequal weights (10 lb. and 1 lb.) fall simultaneously : "Yet the Aristotelians, who with their own eyes saw the unequal weights strike the ground at the same instant, ascribed the effect to some unknown cause, and preferred the decision of their master to that of Nature herself." It is well known that a sovereign and a feather will fall at the same rate if placed in a vacuum.

In England, Francis Bacon, who lived at the same time as Galileo, foresaw original methods of studying science. In 1605 he published his *Advancement of Learning*, in which he said: "All true and faithful natural philosophy hath a double scale or ladder, an ascendant and descendant ; ascending from experiments to the invention of causes, and descending from causes to the invention of new experiments."

In the *Advancement of Learning*, Bacon pointed out the chief defect in Science, which was the disregard of experiment. He abandoned the deductive logic of Aristotle, in which preconceived theories were set up without reference to actual fact, and which led to elaborate conclusions never tested by experiment. Bacon said we should rely upon the result of experiment ; conclusions were

to be drawn from facts alone, and the work was to be done on a definite system.

Bacon cannot be described as a scientist, but in addition to his great literary work, and while engaged upon it, he made some shrewd observations. He rightly described heat as a mode of motion ; not a thing *per se,* as had been supposed. He stated also that light required time for transmission, and it was found later that its velocity is 186,000 miles per second. He was right in these statements, but he erred in rejecting the theory of Copernicus that the Sun and not the Earth was the central body of the solar system.

It was during the period when Bacon was attending the Court of Queen Elizabeth that Dr. William Gilbert, who was one of Her Majesty's physicians, made the discovery that glass, sulphur, resin, etc., possessed the same property as amber and jet ; they attracted light objects when rubbed. It was not the teaching of Bacon which led Gilbert to fall back upon experiment, for the *Advancement of Learning* was not written until a later date ; but it is possible that Bacon influenced Gilbert to some extent.

It was Gilbert who coined the word "electricity" from the Greek word *electron* (amber), and in our present-day word "electron," we have a fitting memorial to the first electrical experiment of rubbed amber.

Before considering the experiments which led up to our present knowledge, it will be of interest to make ourselves acquainted with modern theories.

The atom of matter has become a very prominent subject in recent years, but it had its beginning more than two thousand years ago, and in this connection the name of Democritus is well known. This illustrious Greek philosopher lived in the fifth century B.C. He was by far the most learned thinker of his age. Among the few fragments of his work which have been handed down to us, there is the "Atomic System," which seems to have been founded by Leucippus a hundred years earlier.

Leucippus and Democritus assumed an infinite multitude of indivisible particles or atoms, and attributed to these a primary motion, which brought them into contact with one another and produced the realm of Nature.

Democritus is credited with explaining that matter cannot be destroyed, and that all changes are due to the combination and separation of particles. The word "chance," according to this philosopher, is only an expression of human ignorance. He said that nothing happened by chance, but that every occurrence had its cause from which it followed by necessity. He declared that the only existing things were the atoms and empty space, and that all else was mere opinion. He thought of the atoms as infinite in number, and infinitely various in form. He pictured collisions between the atoms, and explained that from the lateral motions and whirlings of the atoms arose the beginnings of worlds. He accounted for the variety of things by the varieties

of atoms, the difference in things being due to the number, size and aggregation of the atoms.

Two hundred years ago John Dalton advanced a new phase of the atomic theory. Some years previously, William Higgins had suggested that each chemical compound was definite in the atomic sense, but Dalton did not know of Higgins' work; Dalton was the first to form an atomic theory based upon the results of experiments. The conception arrived at by Dalton in 1808 remains the foundation on which all modern chemistry is built.

Robert Boyle (1626–91) was the first to give the word "element" a scientific definition. He said that an element is a substance which resists analysis. It consists of one kind of matter, and by no process known to us is it possible to extract from it any other substance.

The fact that there were definite proportions of elements in compounds was known before Dalton's time, but it was he who supplied an explanation of the observed facts. He assumed the ancient theory of atoms, and declared that each element consists of particles, all alike in size, weight and chemical properties. He was the first to point out that when the elementary substances enter into chemical union with each other to form compounds they combine according to definite laws. He stated three laws known as—(1) Definite proportions; (2) Multiple proportions; and (3) Equivalent proportions. The meaning of these is:

(1) When two or more elements combine to form a compound, they combine in constant proportions by weight.

(2) The second law states: When two or more elements combine to form more than one compound, they combine in simple multiple proportions. The elements Oxygen and Nitrogen unite in different proportions to form five different compounds. A Nitrogen atom may be united to one, two, three, four or five atoms of Oxygen.

As an example of the third law, by chemical methods we can remove one element from a compound and replace it by an equal number of atoms of another element; we can observe how much this alters the weight of the compound, and thus we can compare the weight of one kind of atom with the weight of another.

According to Dalton's view the atom was a particle which could not be divided. Each elementary substance is composed of atoms, exactly alike, of which the weight is constant, but the atoms of one element differ in weight from those of another element. We picture a particle or molecule of water as composed of two atoms of Hydrogen and one atom of Oxygen, and this is written by the chemist as H_2O. A molecule of water is an ultra-microscopic object, and measures only one-millionth of a millimetre in diameter. This molecule contains two atoms of Hydrogen and one of Oxygen, and these are not in contact with each other, but are in rapid motion. In chemistry the actual weight of an atom is out of the question,

but their relative weights can be determined with great accuracy. Beginning with the idea that atoms are all united in the simplest possible manner, Dalton proceeded on the principle that when two elements unite to form only one compound, the molecule of the compound is composed of one atom of each element; that when two elements unite to form two compounds the molecule of one compound is composed of one atom of each element, while the molecule of the second compound is composed of one atom of the one element and two atoms of the other element; and so on. He then ascertained the proportions by weight in which the elements are united in their compounds, and, by applying the above principle, he arrived at the atomic weights of the elements. These may be tabulated in the manner shown on next page. The following rare elements have not been included in the list :—*Masurium, Illinium, Europium, Dyspiosium, Holmium, Lutecium, Hafnium, Rhenium, Polonium, Eca-Iodine, Niton, Eca-Caesium, Actinium,* and *Brevium.*

ELEMENTS, WITH ATOMIC WEIGHTS

Hydrogen (H)	1·008	Zirconium (Zr)	90·6
Helium (He)	4·00	Columbium (Cb)	93·1
Lithium (Li)	6·94	Molybdenum (Mo)	96·0
Beryllium (Be)	9·1	Ruthenium (Ru)	101·7
Boron (B)	10·9	Rhodium (Rh)	102·9
Carbon (C)	12·0	Palladium (Pd)	106·7
Nitrogen (N)	14·008	Silver (Ag)	107·88
Oxygen (O)	16·0	Cadmium (Cd)	112·4
Fluorine (F)	19·0	Indium (In)	114·8
Neon (Ne)	20·2	Tin (Sn)	118·7
Sodium (Na)	23·0	Antimony (Sb)	121·77
Magnesium (Mg)	24·32	Iodine (I)	126·92
Aluminium (Al)	26·96	Tellurium (Te)	127·5
Silicon (Si)	28·3	Xenon (X)	130·2
Phosphorus (P)	31·04	Caesium (Cs)	132·81
Sulphur (S)	32·06	Barium (Ba)	137·37
Chlorine (Cl)	35·46	Lanthanum (La)	139·0
Argon (A)	39·9	Cerium (Ce)	140·25
Potassium (K)	39·10	Præsodymium (Pr)	140·6
Calcium (Ca)	40·07	Neodymium (Nd)	144·3
Scandium (Sc)	45·1	Samarium (Sm)	150·4
Titanium (Ti)	48·1	Gadolinium (Gd)	157·3
Vanadium (V)	51·0	Terbium (Tb)	159·2
Chromium (Cr)	52·0	Erbium (E)	167·7
Manganese (Mn)	54·93	Thulium (Tu)	168·5
Iron (Fe)	55·84	Ytterbium (Yb)	173·5
Nickel (Ni)	58·68	Tantalum (Ta)	181·5
Cobalt (Co)	58·97	Tungsten (W)	184·0
Copper (Cu)	63·57	Osmium (Os)	190·9
Zinc (Zn)	65·37	Iridium (Ir)	193·1
Gallium (Ga)	70·10	Platinum (Pt)	195·2
Germanium (Ge)	72·5	Gold (Au)	197·2
Arsenic (As)	74·96	Mercury (Hg)	200·6
Selenium (Se)	79·2	Thallium (Tl)	204·0
Bromine (Br)	79·92	Lead (Pb)	207·2
Krypton (Kr)	82·92	Bismuth (Bi)	209·0
Rubidium (Rb)	85·45	Radium (Ra)	226·0
Strontium (Sr)	87·63	Thorium (Th)	232·15
Yttrium (Y)	89·33	Uranium (U)	238·2

When the symbols are not derived directly from the names of the elements, they are taken from the Latin names, as follows: Iron (*Ferrum*, Fe); Copper (*Cuprium*, Cu); Gold (*Aurum*, Au); Antimony (*Stibium*, Sb); Lead (*Plumbum*, Pb); Mercury (*Hydrargyrium*, Hg); Potassium (*Kalium*, K); Silver (*Argentium*, Ag); Sodium (*Natrium*, Na); Tin (*Stannum*, Sn); Tungsten (*Wolfram*, W).

It was natural for Dalton to take hydrogen as the unit, because it is the lightest substance known.

The next big forward step was taken by the French chemist and physicist—Gay-Lussac (1778–1850)—who studied the proportions by volume in which gases combine with each other; gases may combine to form liquids. The results of his investigations may be summed up as follows:

1. Two gases always combine in simple proportions by volume, and the volume of the gaseous product stands in the simplest relation to the volumes of the constituents. For instance, to take a very simple case, 1 volume Hydrogen + 1 volume Chlorine = 2 volumes Hydrochloric Acid which is written by the chemist, HCl.

At first this theory of Gay-Lussac did not seem to fit in with Dalton's atomic theory, for it involved the assumption that equal volumes of gases contain equal numbers of atoms, and Dalton brought forward experimental proof that this is impossible. But the difficulty disappeared when Avogadro (1776–1856), Professor of Physics

at Turin, suggested that there was a difference between the *atom* and the *molecule.* He pointed out that although the molecule is the smallest particle of a substance which can exist in a free state, it is not the ultimate particle, that a molecule of a compound is composed of atoms of two or more different kinds, while a molecule of an elementary substance is composed of two or more atoms of the same kind. He suggested that while the molecule of water is composed of three atoms (two Hydrogen and one Oxygen), the molecule of Hydrogen is composed of two atoms of Hydrogen, while two Oxygen atoms go to make a molecule of Oxygen. Avogadro was led to suppose that equal volumes of all gases, under similar conditions of temperature and pressure, contain equal numbers of *molecules* (not *atoms*). If this be accepted, then it follows that the proportion between the weights of the molecules is the same as the proportion between the weights of equal volumes, or the relative densities, of the gases. This gave an experimental method of determining the relative weights of the molecules of all substances which can be converted into the gaseous state without undergoing decomposition. Hydrogen being the lightest known substance, its molecule was again chosen as the standard for comparison. The term "molecular weight" is understood to mean the weight of the molecule of any substance as compared with the weight of a molecule of hydrogen.

In a large number of compounds containing any one element it is probable that one at least of

these compounds will contain only one atom of the element in its molecule. Therefore, when the composition and the molecular weights of each of the compounds are known, the smallest weight of the element which enters into the molecule of any of its compounds is taken as the atomic weight.

As it is of the first importance that the relative weights of the elementary atoms should be ascertained with the greatest possible accuracy, any means of checking the results obtained by the application of Avogadro's theory is of value. One method, discovered by Dulong and Petit, is that the atoms of the solid elements have the same capacity for heat. Another way of putting the matter is to say that if quantities of the different elements be taken proportional to their atomic weights, equal quantities of heat must be imparted to them in order to raise their temperature to the same extent.

The application of the above theory provides another direct method of determining atomic weight, although, of course, the results are only approximate.

There was still another method of determining atomic weight, and this was suggested by the German chemist, Mitscherlick (1799–1863). Different substances sometimes crystallise in the same form; when they do so, they are said to be *isomorphous*. It happens that isomorphous substances are often chemically similar to each other in the sense that their molecules contain the same

number of atoms. According to Mitscherlick, when one element replaces another in an isomorphous crystal of the same chemical character, the substitution occurs in such a way that one atom of the one element replaces one atom of the other. Therefore, if the atomic weight of the one element be known, that quantity of the other which replaces a quantity of the first proportional to its atomic weight, must also be proportional to the atomic weight of the other element. For instance, the Carbonates of Calcium and Barium are isomorphous ; corresponding quantities of the two compounds contain 40 parts of Calcium and 137 parts of Barium respectively ; the atomic weight of Calcium is 40, and therefore the atomic weight of Barium must be 137.

Interesting results are obtained by comparing the values of the atomic weights of the elementary substances with the values of their molecular weights. Assuming Avogadro's law, we find that the molecules of certain elements, notably those of the helium group, are composed of only one atom (called monatomic), and that the molecules of many others, such as Hydrogen, Oxygen and Chlorine, are composed of only two atoms, and are therefore described as *diatomic*, while the molecules of some elements are composed of four or more than four atoms.

In building up molecules of compounds, the atoms have certain definite affinities. For instance, one atom of Hydrogen will combine with only one atom of Chlorine, and forms Hydrochloric

Acid; an atom of Chlorine will combine with only one atom of Sodium, and forms common salt; while one atom of Oxygen will combine with two atoms of Hydrogen and forms water. Again, one atom of Nitrogen will combine with three atoms of Hydrogen, and forms ammonia, and one atom of Carbon will combine with four atoms of Hydrogen and forms methane, which is known as marsh gas or fire damp. The original atomic theory gave no explanation of this property of the atoms; the explanation only came fifty years later, in Frankland's Theory of Valency. Sir Edward Frankland was a Professor of Chemistry, and lived from 1825 to 1899.

According to his theory, the atoms of certain elements are incapable of uniting with more than one atom of another element; these elements are called *monovalent.* Hydrogen and Chlorine belong to this class, but other atoms, such as Calcium and Zinc, can become directly attached to at most two other atoms, and are called *divalent.* Other atoms can be described as being *trivalent, tetravalent, pentavalent, hexavalent,* and *heptavalent.* In order to measure this fixing power of the atoms, Hydrogen is again taken as the unit.

Diagrams and models of the atoms may be made, giving them as many arms as they have fixing powers. Thus, atoms may be represented as in Fig. 1, each arm representing a unit of valency.

When the atoms unite to form a molecule, the arm of one atom joins up with the arm of another

atom. Thus a molecule of water is represented as in Fig. 2.

The use of such diagrams and models is to enable us to form mental pictures of how the

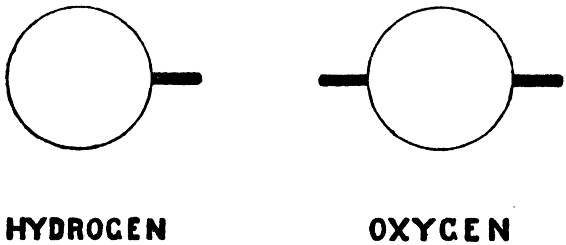


FIG. 1.—ATOMS, SHOWING VALENCY.

Showing the valency or grabbing power of atoms. Hydrogen's atom has only one arm with which it can link on to another atom, while Oxygen's atom has two arms.

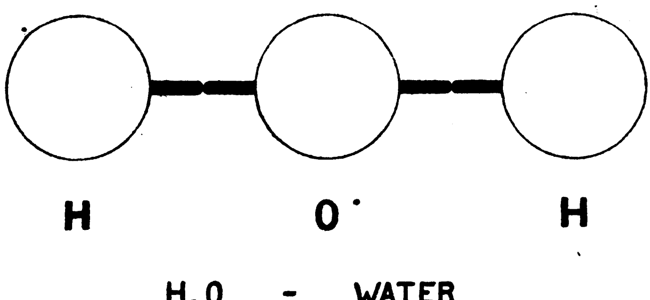


FIG. 2.—A MOLECULE OF WATER.

Showing one atom of Oxygen linked to two atoms of Hydrogen to form a molecule of water.

atoms of matter are united together to form molecules. The theory of valency was a great addition to Dalton's atomic theory.

Early in the nineteenth century, a London doctor, William Prout (1786–1850), suggested that

the atomic weights of all the elements were exact multiples of that of Hydrogen. This idea was opposed by the Swedish chemist, Berzelius (1779–1848), and was set aside ultimately, but we shall see later that we have reason to believe that Prout's idea has something of importance in it.

The next forward step was made by John Newlands, who drew attention to the remarkable fact that, if the elements are arranged in the order of their atomic weights, every eighth element is a kind of repetition of the first. As though it were like the eighth note of an octave in music, the idea became known as "Newlands' Octaves." He made his idea known through a letter in the *Chemical News* (1863), and the support which he could bring forward was very strong. For instance, starting with Potassium, an octave distant in the scale is Sodium, and every one who has handled these metals knows their great similarity. They are both so soft that they may be cut easily with a penknife, and they both catch fire when placed on a damp surface, and the chemist tells us that they are chemically alike. This suggestion of octaves did not receive at the time the attention which it deserved, but later it was brought forward by two workers independently, by the Russian chemist, Mendeléeff (1834–1907), and the German chemist, Meyer. They pointed out that if the elements are arranged in the order of their atomic weights, a variation in the properties of the elements is observed in passing from member to member of the series,

and that elements which have the same characteristics occur in the series at approximately equal intervals. They came to the conclusion that the chemical and physical properties of the elements are periodic functions of their atomic weights. This generalisation became known as the Periodic

GROUPS:— PERIODIC TABLE

SERIES	ZERO	1	2	3	4	5	6	7	8	9	10
1		1·008 H									
2	4 He	6·94 Li	9·1 Be	10·9 B	12 C	14·008 N	16 O	19 F			
3	20·2 Ne	23 Na	24·32 Mg	26·96 Al	28·3 Si	31·04 P	32·06 S	35·46 Cl			
4	39·9 A	39·1 K	40·07 Ca	45·1 Sc	48·1 Ti	51·0 V	52 Cr	54·93 Mn	55·84 Fe	58·68 Co	58·97 Ni
5		63·57 Cu	65·37 Zn	70·1 Ga	72·5 Ge	74·96 As	79·2 Se	79·92 Br			
6	82·92 Kr	85·45 Rb	87·63 Sr	89·33 Y	90·6 Zr	93·1 Cb	96 Mo		101·7 Ru	102·9 Rh	106·7 Pd
7		107·88 Ag	112·4 Cd	114·8 In	118·7 Sn	121·77 Sb	127·5 Te	126·92 I			
8	130·2 X	132·81 Cs	137·37 Ba	139 La	140·25 Ce	140·6 Pr	144·3 Nd	150·4 Sm			
9											
10				173·5 Yb		181·5 Ta	184·0 W		190·9 Os	193·1 Ir	195·2 Pt
11		197·2 Au	200·6 Hg	204 Tl	207·2 Pb	209 Bi					
12			226 Ra		232·15 Th		238·2 Ur				

FIG. 3.—PERIODIC TABLE.

Law, and a Periodic Table was suggested. For convenience, the chemical symbols are used in the above Periodic Table. The meaning of these symbols is given in the list of elements on page 36.

When the Periodic Table was first constructed, there were numerous blank spaces, and Mendeléeff

was bold enough to predict, not only the existence of elements to fill some of the gaps, but to state what their chief properties would be. These elements did turn up in the later discoveries of Gallium, Germanium and Scandium.

Another late arrival in the Periodic Table is Radium, which was discovered by the Curies in 1896. Some of the rare elements are not included in the table, but these are mentioned on page 35.

CHAPTER III

THE ELECTRICAL STRUCTURE OF MATTER

A VERY special interest lies in the electrical structure of the atom, and it will be helpful to trace its development. The greatest support to this theory was the discovery of the electron, or particle of negative electricity. Later, we shall consider the experiments by which this and other knowledge was obtained. It was observed that the electron must be a constituent of all atoms of matter, for all electrons were found to be identical, no matter from what source they were obtained. Bodies when incandescent give off electrons. It became apparent that the electron was a common unit in the structure of atoms. Sir J. J. Thomson, of Cambridge, discovered the electron in 1897, and he played a very prominent part in the development of the electron theory.

The discovery of Radium gave much support to the idea of the electrical structure of matter, for electrons were detected escaping from Radium. The atoms of Radium were exploding (only one in one million billion atoms explodes per second), and it is during the explosion of such Radium atoms that the electrons are set free.

As already stated, an atom could not be

composed entirely of electrons, for particles of negative electricity will not remain together without a controlling force, as they are self-repulsive. It was evident that there must be an equivalent of positive electricity.

In the absence of the discovery of any positive particle, the idea of a sphere of positive electricity was suggested, and the electrons were contained within this sphere.

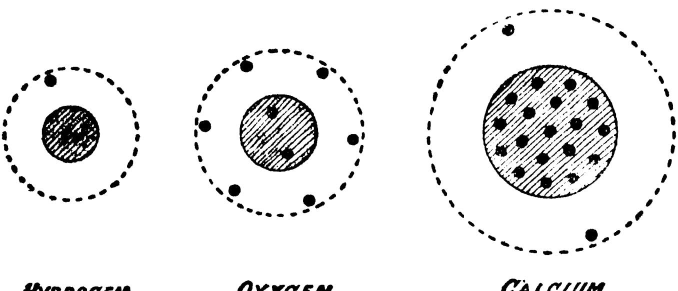


FIG. 4.—ATOMS WITH POSITIVE SPHERES.

The amount of positive electricity exactly balanced the amount of negative electricity (electrons), some electrons revolved like satellites.

Here was the mental picture of some of the atoms at that time (Fig. 4).

The outer ring of electrons explained both chemical and optical phenomena. Some atoms could accept an additional electron, while others could give up an electron, and this interchange of electrons set up a difference of the electric condition of the atoms, one becoming negatively electrified by the gain of a particle of negative electricity, while the other became positively electrified by the loss of a negative particle, thus

leaving a surplus of positive electricity. There is no transference of positive electricity as the positive particles are well anchored within the atoms of matter. Unlike electricities attract one another, and this electrical attraction between atoms explained *chemical affinity* and the *chemical union* by which atoms combine together to form molecules.

All the electrons forming the atom were pictured as being in rapid motion, the outer ring being a large orbit around the sphere. The movements of these outer electrons accounted for several phenomena.

So early as 1881, Sir J. J. Thomson had shown that a charged body in motion behaved as if it had an additional electric mass due to its motion. The moving charge generates a magnetic field in the space surrounding it, giving rise to the phenomena of magnetism. The atom has a magnetic field surrounding it, due to the moving electrons within it.

Again, the rings of electrons, while making their rapid journey around the centre of the atom, were supposed to be capable of vibrating, and such vibrations set up a series of waves in the surrounding ether, and in this way the production of light was accounted for. Different rates of vibration set up different frequencies of waves, and those which affect our eyes stimulate the different sensations of colour.

The positive sphere has been abandoned in favour of a small nucleus containing positive

electricity and electrons. One of the main difficulties has been to know in what form the positive electricity exists. Recent investigations support the idea that the positive particle is identical with the nucleus of the hydrogen atom, the hydrogen atom being composed of one particle of positive electricity and one of negative, as shown in Fig. 5. No evidence has been obtained of the existence of a positively charged unit of mass less than that of the hydrogen nucleus, and we shall see later how we are able to experiment with these positive particles, which have been named *Protons.*

The mass of the proton is 1800 times that of the electron, but the proton is much smaller in size. No explanation can be offered regarding the difference between positive and negative electricities, but it would not be wise to be dogmatic and say that the hydrogen nucleus is the unit of positive electricity, as there is the possibility of further discovery. As already stated, one mental picture is that the proton is as it were a solid vortex of ether, while an electron is a hollow, empty vortex.

When we speak of the mass of the proton being 1800 times that of the electron, we do not refer to surface or cubic area. The greater mass of the proton is to be explained by supposing that the distribution of electricity is much more concentrated for the proton than for the electron. If we picture the shape of these to be spherical, the radius of the proton should be only $\frac{1}{1800}$th

that of the electron, which makes the proton the smallest particle known to us. However, all this is hypothetical.

Here is a mental picture of the atoms composed of electrons (shown as dots), and protons shown as positive signs (+) (Fig. 5).

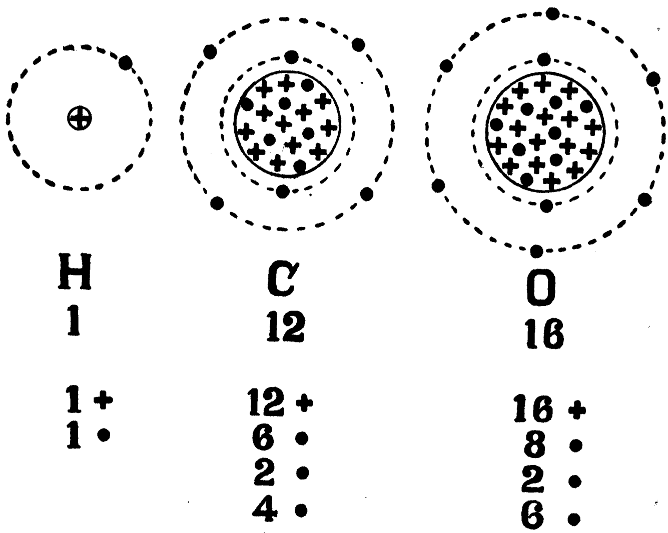


FIG. 5.—ATOMS WITH NUCLEI.
Protons are represented by + signs and electrons by dots. There is an equal number of protons and electrons in each atom.

It will be observed that there are more protons than electrons in the nucleus, which therefore possesses a positive charge. This is balanced by the addition of electrons surrounding the nucleus, so that the total number of electrons in the atom is the same as the total number of protons. At the centre of each atom is this positively charged nucleus of dimensions minute compared with the

diameter of the atom, and, as stated, this nucleus is surrounded by negative electrons, the distribution of which extends to a distance, and occupy rather than fill a region, the diameter of which measures about one 200,000,000th part of a centimetre. The mass of the atom resides mainly in the nucleus, while, as already pointed out, the physical and chemical properties of the atom depend upon the number and distribution of the outer electrons.

There are several theories of the construction of the atom, and these are known by the names of the inventors of the theories. The positive sphere atom, already described, may be called the Kelvin atom, as it was Lord Kelvin's suggestion. We must remember that these are merely theories, and that we cannot bring forward any facts to prove how the electrons are arranged within the atom.

In his Bakerian Lecture (1920), Sir Ernest Rutherford gave his views "On the Nuclear Constitution of the Atoms." He pictured an electrically neutral atom having a number of electrons surrounding the nucleus, the number being equal to the number of resultant positive unit charges of the nucleus itself. The hydrogen atom was, of course, pictured as the simplest atom, and, as already pointed out, its nucleus is supposed to be the positive unit. As already stated, its dimensions are exceedingly small compared to the negative electron, though its mass is much greater; it is exceedingly dense,

and so the hydrogen atom consists of one electron circling round one positive unit or *proton*, as Rutherford has named it.

The diameter of the nucleus of light atoms is probably of the order of one 100,000,000,000th part of a centimetre; and when two such nuclei collide they may, should the force be sufficient, penetrate each other's structure. Under such conditions only very stable nuclei would be expected to survive the collision undamaged. We shall see later how collisions are brought about in the laboratory.

The helium atoms which are cast out by the disintegrating atom of radium are projected with great force. These *Alpha particles*, as they are called, may be shot across a gas-filled tube. When these flying particles strike matter, their journey is interrupted, some being turned back, so that they describe hyperbolic paths. We shall see later how the experiments are carried out.

Meantime we wish to note that Rutherford accounted for the large deflection of these Alpha particles by assuming that the atom contains a charged massive nucleus of dimensions very small compared with the size of the atom.

In these so-called collisions there is no actual contact; the atoms are surrounded by electromagnetic fields which act as cushions.

Rutherford assumed that the nucleus has an intense field around it.

The fact that the atoms of elements lose the properties of the element upon entering a com-

pound is often a puzzle to many. For instance, common salt is known to the chemist as Sodium Chloride, and its molecule is composed of one atom of Sodium and one of Chlorine. We know Sodium to be a strange metal, catching fire if laid on a damp surface, and we know Chlorine to be a poisonous gas, but we do not find either of these qualities in the compound salt. Why? We say because a compound has not the qualities of its elements. But why not?

The chemical properties of the atom depend upon its outer layer of the electrons surrounding the nucleus of the atom. Sir J. J. Thomson has said: "As this belt (of *electrons*) will be pulled about and distorted by the proximity of other atoms, we should expect that the properties depending on this outer layer of the electrons would not be carried unchanged by an atom through all its compounds with other elements; they will depend upon the kind of atoms with which the atom is associated in the compounds. On the other hand, the electrons in the strata near the centre of the atom will be much more firmly held; they will require the expenditure of much more work to remove them from the atom, and will be but little affected by the presence of other atoms, so that such properties as depend upon these inner electrons will be carried unchanged by the atoms into the chemical compounds. The properties of the real atoms are in accordance with these suggestions."

The next atomic theory to be considered is the

Bohr Atom, which is sometimes described as the *Bohr-Rutherford Atom*. It was invented by Professor Neils Bohr, of Copenhagen. Bohr was led to his theory through a study of the lines in the Spectrum.

We know that these lines are due to electromagnetic waves sent out by electrons. They are wireless messages sent out by the atoms, and it is by such messages that we can tell the kinds of atoms existent in the stars.

The lines may be seen on looking through a spectroscope, but there are many lines which are invisible; these may be detected by photography. The spectroscope is explained later (p. 237).

That prince of experimenters—Professor R. W. Wood, of the United States of America—has succeeded, by means of a special discharge tube, in putting hydrogen into such a state that many lines appear in its spectrum. The intense bombardment of atoms in the stars is capable of carrying matters further than we have been able to do in the laboratory.

Bohr has assumed that in order to have a larger number of lines than hitherto found in the laboratory experiments, the atoms must be far enough apart to allow of the existence of large orbits for the revolving electrons. The high temperature of the stars would bring about this condition. Picturing these electrons revolving in their orbits around the nucleus of the hydrogen atom, Bohr suggested that the radiation, or

wireless message, producing a line in the spectrum, was sent out only when the electrons made an excursion from an outer orbit to an inner orbit. He pictured the orbits arranged as in Figs. 6 and 6A.

It was during the jump from one orbit to another that these radiations were given out. This radiation, or disturbance of the ether, was due to the sudden stop of the electron. This idea took the place of an electron merely vibrating in its orbit, as was supposed in an earlier theory. In both cases, so long as the electrons continued to revolve in a given orbit, at uniform velocity, no radiation was supposed to take place.

The different orbits represent different states of stability, in which the centrifugal force (*due to the speed of the revolving electron*) exactly balances the electro-static attraction of the nucleus, or, in other words, the mutual attraction between the negative electron and the positive nucleus. We have a grand demonstration of the action of central forces in the Moon's revolution around the Earth and of the planets around the Sun.

Bohr assumed that this change from one orbit to another took place in definite jumps, or what is called "quanta," which will be considered in a later chapter. The electron had definite stable positions. These jumps do not take place unless some outside force, such as chemical action, or some bombardment of the atom, such as passing an electric charge through a gas (in a vacuum tube). The glow within a vacuum tube is

accompanied by what we call *ionisation.* This means the detachment of electrons from the atoms, leaving them positively charged.

The Bohr theory of the atom is easily remembered by these jumps from one stable orbit to another.

Structure of the Atom

What the layman wishes to know is how many such rings exist? The answer is that in the case of hydrogen only one ring per atom can exist at one time, but the electron may occupy other rings. Hydrogen can, of course, only have one ring at a time, because it has only one electron, and it is evident that the more electrons an atom has revolving around the nucleus, the more rings there may be. But speaking of atoms in their normal conditions, all the electrons confine themselves to four rings which, reading from the centre, are called K, L, M and N rings. Only the heaviest atoms will have electrons in the N rings.

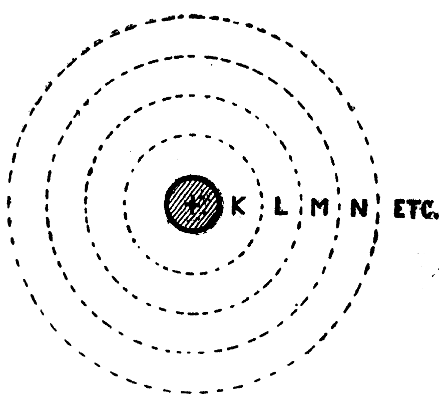


FIG. 6.—THE RINGS OF AN ATOM.
These rings are the orbits in which electrons may revolve around the nucleus.

Those beyond the N ring are possible levels to which the electron does jump, but which are not occupied by electrons, while the atom is in its normal condition.

Another question the layman will no doubt ask is regarding the jumps from one ring to another. Collisions may knock an electron from one ring to another nearer the centre; chemical action, which includes combustion, may also cause the electron to jump to rings nearer the centre, but whatever outward force causes the jump, the result is the same—the electron, in jumping back, disturbs the ether and radiates energy through the ether, which, as pointed out already, is the field in which all energy exists.

Still another question about these rings. How many electrons can a ring hold? The K ring is full when it has two electrons, the L ring is not full till it has eight electrons, while the M ring is fully occupied by eighteen electrons. The N ring is more accommodating, and may have any number up to thirty-two electrons, but the outside ring has usually only eight electrons in it.

It should be understood that while these figures given are the maxima for the various rings, the rings do not always contain their maxima; in a ring which can hold eight electrons, there may only be seven or less forming different elements, but if an electron is missing from a ring which is normally full, its place will tend to be taken by an electron from one of the neighbouring rings, or even from outside the atom.

It is evident that the electrons must also jump from an inner to the next outer ring, and another inquiry will be as to the cause of such jumps. The answer is that an electron jumps outwards when it absorbs radiant energy.

It is natural that it is the atoms in the outermost ring which are most easily knocked about.

Another point of interest is that the electron in making a jump sends out a wireless message intimating its position. Each ring of an atom has a definite frequency of radiation. We see why the heavier atoms provide most lines in the spectrum; they have more wireless operators to occupy a greater number of rings.

It will be clear to the reader that a spectral line indicates a jump from an outer to another inner ring, and that the position of the line in the spectrum indicates the frequency of the radiation, and that in this way the elements in the stars have made themselves known to us.

It will also be clear how it is that the elements in the stars provide more lines than the same elements do in the laboratory. It is because the atoms under the high stellar temperature make more violent collisions with one another, and also because the atoms are further separated from one another, providing room for more rings.

Hydrogen in the stars has sent us a great variety of different wireless signals, indicating as many levels, but these are not orbits which the electrons could occupy in the hydrogen known on the Earth.

Another physicist (Sommerfield) has added to the Bohr theory, the effect of varying speeds in elliptic orbits; an atom may have both circular and elliptical orbits.

The idea of energy existing in units or quanta is difficult to grasp until we can realise that energy is an entity, and we come to recognise gradually that energy and matter are so closely related to one another that we are not altogether

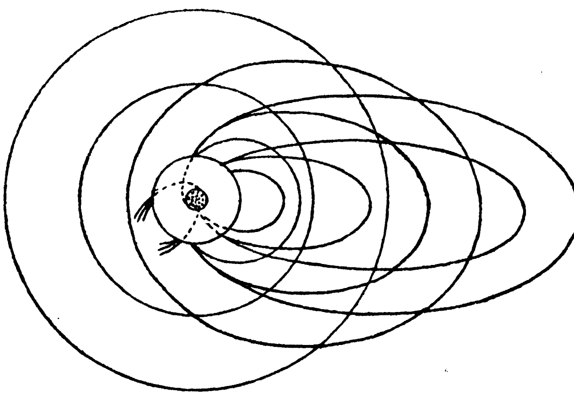


FIG. 6A.—ATOM WITH ELLIPSES.

surprised to learn that we may think of matter as a form of energy, the atom being a miniature system of revolving electrons. Matter becomes radiation. Indeed, we may say that matter disappears when radiation is produced. Think of the enormous energy being sent forth by the Sun at the expense of matter. The Sun is losing matter every second, but this subject will be dealt with later.

Another theory of the atom is known as the

Langmuir or Lewis-Langmuir atom. Sir J. J. Thomson prepared the way for this theory. He said: "If we assume that the recognised laws of electrical action hold good for the small charges carried by the electrified parts of the atoms, we can, by the aid of mathematical analysis, get some idea of the way in which a number of electrons will arrange themselves when in stable equilibrium. We find that in a symmetrical atom only a limited number of such electrons can be in equilibrium. When the number of electrons exceeds this critical number, the electrons break up into two or more groups, arranged in a series of concentric shells, like the layers of an onion. The number of such layers depends upon the number of electrons in the atom, and this again is dependent upon the atomic weight. The electrons in the outside layers will be held in their places less firmly than those in the inner layers; they are more mobile, and will arrange themselves more easily under the forces excited upon them by other atoms."

Sir J. J. Thomson goes on to show that the social qualities of the atom will depend mainly on the outer belt of electrons, and how the transition of an electron from this outer ring to the outer ring of another atom capable of receiving it, there is brought about what we know as chemical union, but we have dealt with this matter already.

While the existence of these rings were merely suggestions made by Sir J. J. Thomson, it is interesting to note that this has been confirmed by experiment. Professor Barkla has shown that,

when submitted to appropriate treatment, each atom gives out special kinds of Röntgen rays. A platinum atom gives out one kind of ray, a silver atom another, with a longer wave-length than the platinum one. Barkla has shown the kind of radiation to be connected with the atomic weight, and this connection shows that these rays arise from similar parts of the atoms, and the evidence is very strong that they originate in the innermost rings of electrons. These radiations are what we call Hard X-rays, and are due to shorter waves than those which constitute Soft X-rays.

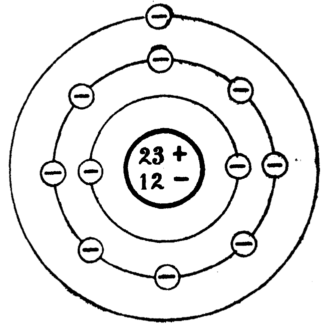
The lighter elements give out exceedingly soft rays, and if the element is lighter than an atomic weight of 23 (Sodium), the rays are presumably so soft that they cannot be detected. These soft rays probably arise from the second shell of electrons, the K, L and M rings of the atom, counting from the inside of the atom. In this way we get at least two rings of electrons.

The Langmuir atom differs from the other theories in having the shells of electrons at rest instead of being in rapid revolution. He pictures them as either being at rest or vibrating about definite points.

The arrangement of the nuclear atom is shown in Fig. 7.

There are only two electrons in the innermost shell, while there are eight in the next shell, and these arrange themselves in positions corresponding to the eight corners of a cube.

His theory is that the electrons tend to surround the nucleus in successive layers containing two, eight, eight, eighteen and thirty-two electrons as the number of electrons increase. He pictured the atoms being linked together by one or more "duplets," held in common by the complete sheaths of the atoms. The static atom of Langmuir is a simpler atom than in the other theories, because it gives a better picture of chemical compounds. It has been very successful in accounting for the general chemical qualitative properties of many of the elements, and in predicting those of the compounds.



ATOM OF SODIUM

FIG. 7.

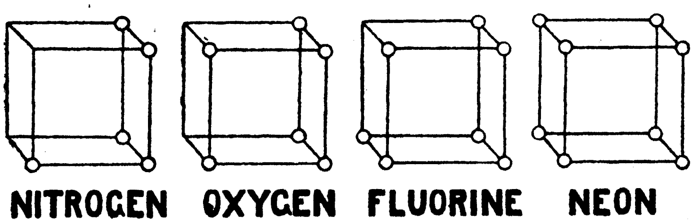
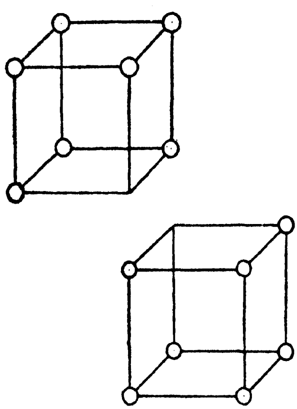


FIG. 8.—CUBICAL ATOMS.

These atoms link together by sharing an electron. Note the empty corners.

Fig. 8 shows the cubical atoms of Nitrogen, Oxygen, Fluorine and Neon.

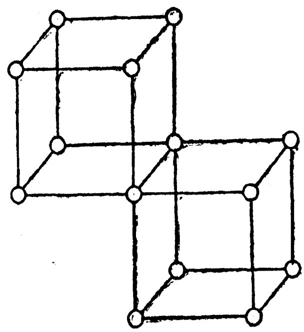
These models are helpful in dealing with chemical union, but they do not help us to picture radiation. The sharing of electrons in the union of the atoms is of special interest, and is shown



TWO ATOMS FLUORINE

FIG. 9.

These are seen, in Fig. 10, united together to make a molecule.



TWO ATOMS FLUORINE UNITED MAKE A MOLECULE

FIG. 10.

Compare this with Fig. 9, and the method of union is apparent.

in Fig. 9, in which we see two atoms of the element Fluorine, and in Fig. 10 we see them united.

It will be of interest to consider the behaviour of electrons when free from the atoms of matter.

CHAPTER IV

ABOUT ELECTRONS

ELECTRONS, which form part of the atom, may be removed from it, and from one object to another. It is the excess or deficiency of these electrons which gives to an object an electric charge.

When a glass rod is rubbed, the process of rubbing removes electrons from the glass to the rubber, thence to the hand, and then to earth, leaving the glass with a surplus of positive electricity; the positive charges remain within the atoms. The rubber would have an accumulation of electrons but for their escape to earth. We can insulate the rubber, whereupon it is found to have a negative charge.

When a vulcanite rod is rubbed, electrons accumulate upon the rod, and cause a preponderance of electrons, so that it becomes charged with negative electricity. Our planet Earth has a negative charge, due to the arrival of electrons shot off by the Sun.

The old statement that " equal quantities of the opposite electrifications are always produced simultaneously " has a new meaning in the light of the electron theory. It is simply a case of the

removal of a definite quantity of electrons from one place to another, leaving a corresponding surplus of positive electricity.

This removal of electrons from an object is often done without intention, as in the combing of a lady's hair. I remember seeing a length of woollen cloth electrified by being drawn over a wooden table, for examination in a factory, and the electrification was sufficient to produce a considerable electric shock.

The discharge of a negatively electrified body is due to the repulsion of like electricities; and the discharge of a positively electrified object is due to its attracting a corresponding negative charge; in both cases, Nature is bringing the condition to an equilibrium.

It is these roaming or free electrons which produce an electric current, under the influence of a chemical battery or a dynamo; they constitute a regular drift of electrons from atom to atom of the conductor. The rate of progression is very slow, being a few yards per hour, but as the drift takes place all along the line simultaneously, the effect at the distance is immediate. There is only a negative flow, as the positive particles remain anchored within the nuclei of the atoms of metal in the conductor.

In the case of a battery, the drift is all in one direction, and in a battery in which carbon and zinc are the two elements, the drift is from the carbon through the liquid to the zinc, as in Fig. 11.

Hence the drift outside the battery is from the zinc to the carbon, and we used to speak of the positive current travelling in the opposite direction to that (from the carbon to the zinc), but now we know that there is no positive current, the protons not being free to move. Until the discovery of electrons we thought the current flowed in that direction, but now we know that the phenomenon is due to a steady progression of electrons in the opposite direction.

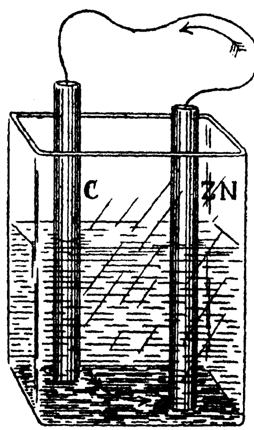


FIG. 11. — DIRECTION OF ELECTRIC CURRENT IN CELL.

The arrows show the direction of drift of the electrons.

We picture the action in the case of a dynamo to be electrons merely surging to and fro within the revolving armature wires. The electrons pass to and fro from atom to atom, and make no real progression. This to-and-fro movement constitutes what we call an *alternating* electric current. If we connect the armature to the mains, as in Fig. 12, we have a similar alternating current in the mains, but if we connect the mains through a commutator in the dynamo, as in Fig. 13, we cause a regular drift of electrons, or a direct or continuous current in the mains. We allow the to-and-fro movement of the electrons in the armature to nudge their neighbours in the mains into action.

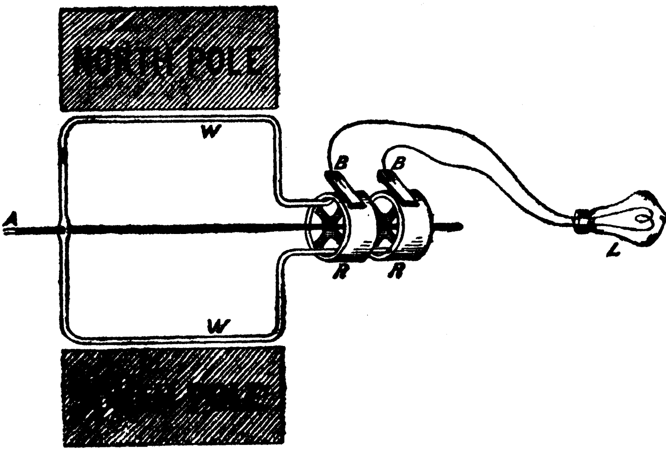


FIG. 12.—ALTERNATING DYNAMO.

WW represents the armature, *RR* the rings attached to the ends of the coil, *BB* the brushes for leading out the current to the lamp *L*. The coil is seen revolving between the poles of the magnet.

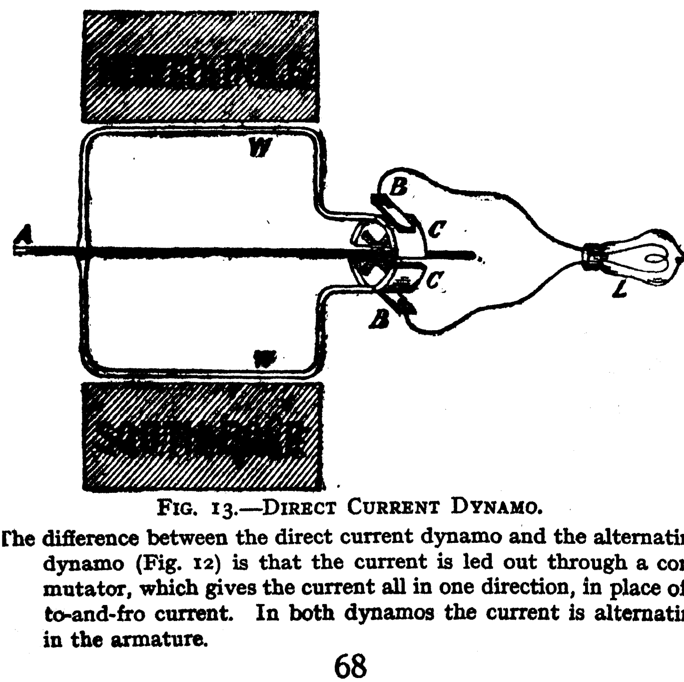


FIG. 13.—DIRECT CURRENT DYNAMO.

The difference between the direct current dynamo and the alternating dynamo (Fig. 12) is that the current is led out through a commutator, which gives the current all in one direction, in place of a to-and-fro current. In both dynamos the current is alternating in the armature.

and as the contact through the brushes alternates as the coil revolves, the electrons are always urged in the one direction, and the result is a steady progression in the mains under the influence of the alternating electricity in the armature coil. In these ways we may lead out from a dynamo either an alternating or a direct electric current.

But what happens when the electrons move? They disturb the surrounding ether of space, and it is through the ether that the energy is trans-

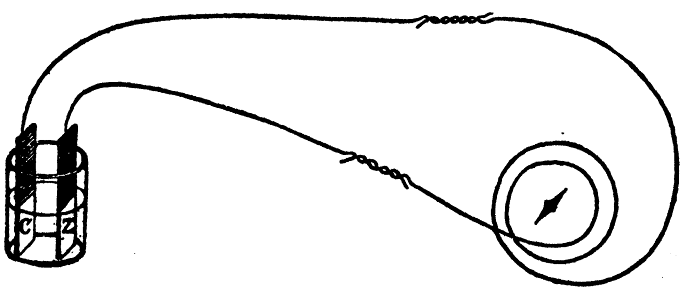


FIG. 14.—AN ETHER DISTURBANCE.
The movement of electrons in the wire causes an electro-magnetic field around the wire; the magnet is moved by this.

mitted. This is apparent in the simple needle telegraph (Fig. 14).

The electrons are marching through the conducting wire; they do not come in contact with the magnetic needle, but they disturb the surrounding ether, and this disturbance is intensified by the coil. We see the magnet move round under the influence of this ethereal disturbance; the energy is transmitted through the ether, as all energy is.

We see that the electric current has an electro-

magnetic effect. We picture magnetism itself as due to the movement of electrons within the atom. It is these moving electrons which produce the magnetic effect (Fig. 15).

We may take Fig. 14 with the battery and magnetic needle as an aid to the meaning of magnetism. We picture the little magnet to

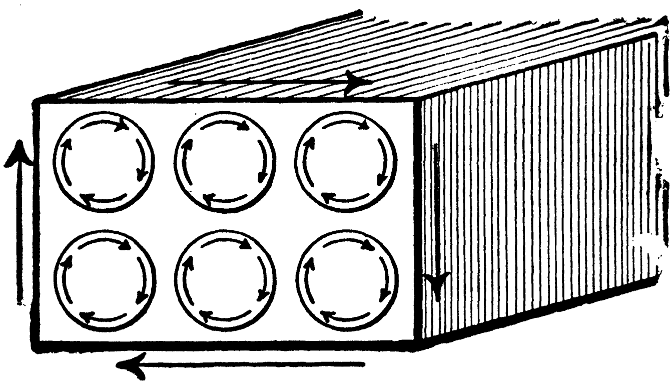


FIG. 15.—MAGNETISM.

The circles represent atoms with revolving electrons. There are myriads of these atoms in a magnet. The effect of the moving electrons is as though they were moving round the magnet, and the electro-magnetic field is due to the movement of these electrons.

represent a molecule of the iron core in an electro-magnet, around which an electric current is being sent by means of the battery and coil of wire. Each molecule of iron has an electro-magnetic effect, due to the rotational movement of electrons within it, but these molecular magnets are all linked up in chains so that they neutralise each other. When the surrounding ether is disturbed by the march of electrons in the coil, these

infinitesimally small magnets take up definite positions just as the needle in the needle telegraph (Fig. 14) does, so that the North Poles all act in unison, and produce the phenomena of magnetism. This state of affairs continues so long as the electrons are kept moving along in the wire forming the coil. The moment that the movement ceases through the withdrawal of the battery influence the magnetism disappears, unless the magnet is very long.

In the case of a permanent magnet made of steel, the molecular magnets do not revert to their neutralised or chain condition, but remain in concerted action. They may be freed from these positions by heating the magnet, in which case the molecules are caused to vibrate and get free from one another; and they settle down in chains as before, and the magnetism is found to have disappeared, though we know it still exists within the molecules. We can understand the meaning of magnetic saturation when all the molecules have been set in position; we cannot add more magnetism. We have seen that the movement of electrons disturbs the surrounding ether; and it almost goes without saying that the to-and-fro movements of electrons will produce waves in the surrounding ether.

Electrons surging to and fro in a wireless aerial produce those electric waves which carry intelligence through space.

A favourite analogy with the present author is that of a boy standing in a pool of water and

making waves on the surface of the water by means of a float to which is attached a pole to form a suitable handle. The boy may make a representation of wireless waves by slow movements of the float, thus producing water waves with a comparatively long distance between their crests, and these we call *long waves.* We know that light, radiant heat, X-rays, etc., are all similar in character to wireless waves; all are transverse waves in the ether of space. If the boy wishes to represent light he must move his

WIRELESS WAVES	RADIANT HEAT	VISIBLE LIGHT	ULTRA VIOLET RAYS	X RAYS	GAMMA RAYS

FIG. 16.—ETHER WAVES CLASSIFIED.
The waves become shorter as you read from left to right. A more detailed diagram is given on page 200.

float much more rapidly and produce a series of waves with a short distance between the crests, and which we call *short waves.* The water waves are giants compared to the invisible ether waves of light.

X-rays are still shorter ether waves.

The gamut of waves which have been detected is shown in Fig. 16.

It will be observed that the ether waves which constitute so-called visible light, which produces the sensation of light, occupy only a very small portion of the scale, as we shall see more parti-

cularly in a later chapter, dealing with ether waves. These waves vary from about $\frac{1}{34000}$th to $\frac{1}{64000}$th part of an inch, and they follow each other at the rate of from 400 billion to 750 billion per second ; that is their *frequency.*

The frequency of most wireless waves is below one million per second, so that the difference between the frequency of these and of light is enormous.

Some years ago I desired to point out what an enormous difference there is between a million and a billion, and I tried to find some suitable analogy.

I took some dried peas and measured a row of them, and, having counted them, I calculated the lengths of a row of a million and of a billion peas. The million row would stretch to a distance of about 4½ miles, while the billion row would go round and round the Earth 180 times ; but that is difficult to visualise, as we cannot picture the size of the Earth. I then tried weighing the peas, but a comparison of their weights was not more helpful. Then I tried the following analogy :

Imagine a tank, holding one million peas, and provided with an automatic trap-door which will eject one pea per second. A simple calculation tells us that the millionth pea will be ejected in about eleven and a half days.

We make a similar tank to hold one billion peas, and we find that the billionth pea will not be ejected until the end of thirty thousand years, so that to see the billionth pea now, the experi-

ment would have had to be begun in prehistoric times, thirty thousand years ago.

A million is to a billion as 11½ days are to 30,000 years.

The difference in frequency of light and wireless waves is of the same order.

It is the difference in frequency which gives us the different colour-sensations. We must realise that colour is merely a sensation within us; outside of ourselves there are only invisible ether waves.

When the waves follow each other at the rate of 400 billions per second, they produce that sensation which we call Red. Then, as the waves increase in frequency, we have the sensations of orange, yellow, green, greenish-blue and blue or violet.

We have infra-red light (below the red) and ultra-violet light (beyond the violet), but these do not produce any sensation of light, though they both may affect a special photographic plate.

In the *Glasgow Medical Journal* (January 1918) I suggested a new colour theory.

The theory is a speculative one, and assumes the presence of a continuous nervous current, and suggests that interruptions to this current constitute nervous sensation. It is analogous to the making and breaking of an electric current in the telephone, which produces a clicking sound in the receiver. So long as there is a steady flow of the current there is no sound; it is the interruption to the current which produces the sensation.

The theory also assumes that the cones in the retina of the eye act as wireless receivers, such as the electrolytic cells, used before the invention of the thermionic valve. In these the arrival of the ether or wireless waves causes a chemical disturbance in the cell, which interrupts an electric current, and this produces a click in a telephone

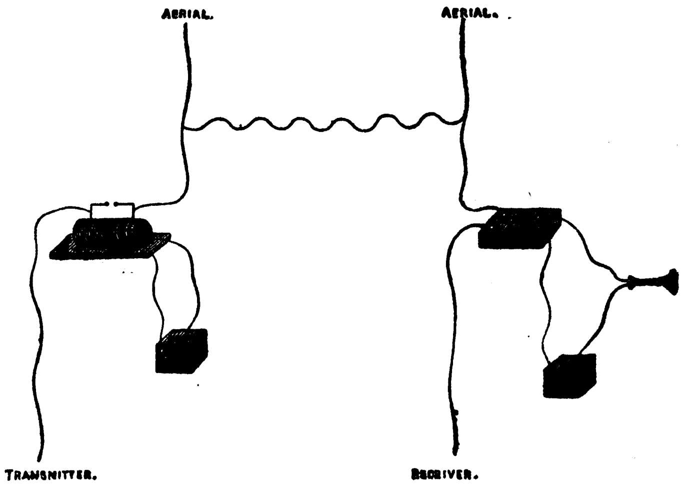


FIG. 17.—ANALOGIES OF COLOUR-PERCEPTION.

receiver. The arrival of the ether waves of light are assumed to cause a chemical disturbance in the chemical condition of the contents of the cones, which disturbs a continuous nervous current, and thus produces a sensation in the brain by way of the optic nerve.

Waves of a certain frequency produce a certain definite interruption which gives us the sensation of Red. Another interruption produces the

sensation of Yellow, another Orange, another Green and so on, each of these being a definite and distinct sensation, not a combination of sensations as was supposed in the well-known and useful Young-Helmholtz theory.

Since the publication of this theory it has occurred to me that it might be extended to the phenomena of sleep and unconsciousness. May these not be due to a temporary cessation of the otherwise continuous nervous currents, during which cessation no sensations can be produced. In waking, this nervous current is restarted, and is again subject to interruption by ether waves; we receive sensations by these disturbances while we are awake, and, in dreaming, the nervous current is started by mental disturbances. Material bodies, when vibrating, send out waves in the surrounding air, and these impinging upon our ears produce the sensation of sound. These air waves act on the tympanum, and interruptions in a continuous nervous current are produced.

Just as sound waves of different frequency produce sensations of different pitch, so the ether waves of light produce sensations of different colours. The sound waves are produced by the vibrating movements of material particles (gong, drum, piano, violin, harp and so on), but no material thing can produce waves in the immaterial ether. We know that an electron may disturb the ether, and set up a series of waves in the ether; the greater the jumps of the electron the higher is the frequency of the resulting waves.

We picture such electrons in the Sun, producing waves which travel ninety million miles to the Earth, while some ether waves take thousands of years to travel from distant stars to the Earth. The paper of this page is reflecting light by means of electrons on its surface. These waves only occur so long as ether waves are falling upon the page, but in some substances, such as Zinc Sulphide, the electrons will continue to vibrate after the withdrawal of the stimulating waves, so that the Zinc Sulphide continues to give out light; it shines in the dark, and is said to be *phosphorescent*. This phosphorescence will disappear after a time if the substance is kept in the dark; the electrons come to rest. They may be thrown into a state of vibration again by allowing light to fall upon them. Sometimes the impinging waves set up a frequency which differs from their own; sometimes invisible rays originate visible ones.

When we know that moving electrons disturb the ether, it is not difficult to realise that movements in the ether, such as wireless waves, can disturb the electrons and cause them to move. In our wireless aerials, when transmitting, we cause electrons to surge to and fro at a definite rate. The result is a series of ether waves, which, on reaching the distant receiving aerial, sets electrons vibrating. A suitable analogy is one already mentioned; that of a boy in a pool of water setting up a series of water waves. When the waves reach a distant cork they cause it to

move up and down with the same frequency as the object producing the waves.

When electrons are shot across a vacuum tube and allowed to bombard a metal target, the electrons within the atoms of the metal send out ether waves of a very high frequency, and these we describe as X-rays. We shall see the important part played by X-rays in arriving at ideas of the constitution of matter.

These X-rays, which do not stimulate vision, may fall upon a screen covered with crystals of Barium platino-cyanide and these fluoresce ; they send out ether waves which come within the scope of our vision. We know how these very short ether waves (X-rays) can penetrate matter which is quite opaque to light.

When an atom explodes, as in the case of radium, some of the displaced electrons produce ether waves even higher in frequency than X-rays—we call these *Gamma rays* ; they may penetrate a granite boulder measuring 6 inches in thickness.

The electron theory has certainly come to stay ; it has been well established, and it will be of interest to see how this knowledge came about.

CHAPTER V

THE DISCOVERY OF THE ELECTRON

We are familiar with the idea of electrons as particles of exceedingly small mass carrying a charge of negative electricity, and we realise that all electrons are identical in every way. We may say that they have no weight.

The electron was discovered by Sir J. J. Thomson in 1897, and until that time the smallest known particle was the atom of hydrogen; it being the lightest of the elements. The electron is not only a little smaller, but is a very great deal smaller than the hydrogen atom; the difference is analogous to that of 1 inch to 150 feet, and is therefore much too large to show diagrammatically in a book, even if we take the electron as a mere dot. If it were possible to lay electrons in a row, there would be 25 billion electrons to 1 inch.

We have seen that the electrons are bricks which go to the making of the atom. We have seen also that the number of electrons in the atom vary, there being one electron in the hydrogen atom, sixteen in the oxygen atom, about two hundred in the lead atom, and so on to the heaviest element, Uranium, which we believe to contain no less than 238 electrons.

We have seen also that the difference in the numbers and arrangements of the outer electrons in the atom explains the chemical properties of the atom.

The history of the discovery of the electron may be said to commence as early as 1859, when Plücker showed that when an electric current passes through a gas at a low pressure, the glass tube in which the gas is contained phosphoresces in the neighbourhood of the negative electrode. We know now that this is due to the glass being bombarded by flying electrons. The glass may be sheltered by placing a piece of mica or metal in the path of the electrons.

Following up Plücker's experiment, Sir William Crookes suggested, in 1879, that matter existed in a fourth condition within the tube, and he called this *radiant matter*. This idea was not accepted, and the phenomenon of what we know now to be a stream of electrons was called the *Cathode rays*. A long controversy ensued as to the nature of these rays. One view was that they were waves in the ether, another that they were due to negatively electrified particles, but not till 1897 were they known to be particles of negative electricity.

Facts were brought forward in support of this theory of particles. It was proved that negative electricity travelled along the direction of the rays, and that the rays could be deflected by a magnet; but against this view it was found that these supposed particles could penetrate thin

sheets of metal, and therefore the cathode stream appeared to be more like rays than particles. The controversy came to an end with Sir J. J. Thomson's discovery of the electron, and his determination of the mass, charge and velocity of the flying particles.

The mass and velocity of the electron were determined by measuring the deflections they experienced when acted on by electric and magnetic forces. The following is a description of the historical experiment. The tube used by Sir J. J. Thomson is seen in the accompanying diagram (Fig. 18).

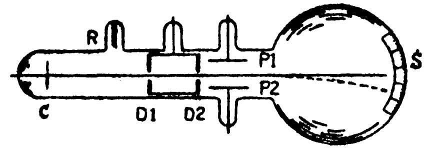


FIG. 18.—MEASURING ELECTRONS.
The deflection of the electrons is shown by the depressed line on scale.

The electrons are shot off from the negative electrode (cathode) *C*, which consists of an aluminium disc supported by a rod of the same metal, and this is connected to an induction coil by means of a platinum wire sealed through the glass.

The positive electrode or *anode* is shown at *R*, and consists of an aluminium rod placed in a side tube. The electrons have to pass through a small hole pierced in a metal disc (*D*1), thus forming a narrow pencil of electrons. After passing through this disc the electrons have to pass through a hole in a second metal disc (*D*2), which still further defines the beam, the hole being smaller than in *D*1. These discs are mounted in a metal tube as

shown in the diagram, but this is merely a matter of convenience. This tube, and also the anode (*A*), are connected to earth, while the electric current from an induction coil is led into the tube at *A* and leaves it at *C*. The electric current in the conducting wires consists of a passing along of electrons from atom to atom, but on entering the exhausted tube in which there is no continuous chain of atoms, the electrons are shot across the

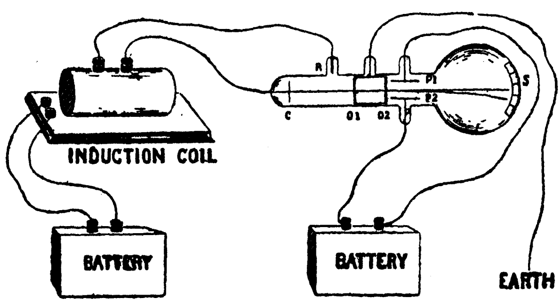


FIG. 19.—ELECTRON APPARATUS.
Showing the apparatus for detecting and measuring the electrons.

tube, and pass through the holes in *D*1 and *D*2, and therefore between the plates *P*1 and *P*2. These plates are made of aluminium and are parallel to one another. They are connected to a large battery of small accumulators, so that one plate becomes positively and the other negatively electrified. The connections are shown in Fig. 19.

The Cathode rays, being composed of particles of negative electricity, will be repelled by the negatively electrified plate, *P*1, and attracted by

the positive plate, *P*2. In this way the narrow beam of electrons is deflected. This deflection is made visible by the particles striking a fluorescent screen (*S*) placed at the end of the tube. The normal beam strikes the screen, as shown by the horizontal line, but the direction of the deflected stream is shown by the under line.

The part of the tube where the parallel plates are is placed also between the poles of an electro-magnet, the magnetic force being at right angles to the stream of electrons, and at right angles also to the electric field when the plates are charged.

The pencil of electrons indicates its position in the phosphorescent screen on which it forms a spot of light.

In the diagram at *S* will be seen a scale which was pasted on the outside of the tube in the original experiment, so that the amount of deflection might be read conveniently.

In making the experiments, the amount of deflection due to the magnetic field was noted first.

From this deflection and the dimensions of the different parts of the tube, it was possible to calculate the radius of the circle into which the beam of electrons was bent. Then the electric field was applied by charging the plates *P*1, *P*2. This was done while the magnetic field was also exerted, due to the electro-magnet being charged. The field was gradually increased until the electrically deflected beam was brought back

to its normally straight path. This showed the amount of electric force required to balance the magnetic force. The ratio of the electric field to the magnetic field is then equal to the velocity of the electrons. The ratio of the mass to the electric charge can then be calculated from the velocity and the known magnetic deflection.

It may all seem very simple, but it was a very difficult thing to perform this experiment. Indeed, at first, no deflection could be got by an electric field. The reason for this was discovered: the passage of the electrons through the gas in the tube caused the gas to become a conductor of electricity, so that the electrons were moving through a conductor which was a complete circuit, and were thus hardly affected by the electric field applied by the plates. This difficulty might seem insurmountable, but it was overcome by using a tube with a very high vacuum.

It is interesting to note in passing that Hertz attempted this experiment but failed; he used too low a vacuum.

When Sir J. J. Thomson succeeded, he made his calculations and found that the velocity of the electrons depended principally upon the electric pressure of the discharge, and to a smaller extent upon the pressure of the gas, while the nature of the electrodes, and the nature of the gas in the tube, also played a part in the results. Even in the same tube there was a variety of velocities, so that there was a spreading of the spot of light on the screen, where it formed what might be

described as a magnetic spectrum. Each point in this spectrum was due to electrons moving with a definite velocity.

These velocities were found to range from about twelve to eighteen thousand miles per second. Such velocities are equal to tens of thousands of miles per minute.

The velocity of the electrons, on reaching eighteen thousand miles per second, come within one-tenth of the velocity of light. No matter what gas was used, or of what element was the negative electrode formed (from which the electrons were shot), and no matter what electric pressure was applied by the induction coil, the ratio of the mass of the electron to its electric charge is always the same.

There is no mystery as to the source of the electrons; these are shot off from the negative electrode. They may be liberated from any material object by bombarding them with X-rays, in which case their velocity is similar to those in the experiment just described. Electrons are liberated also from incandescent metals at high temperatures.

It will be of interest to see how the way was prepared for further advance by some earlier experiments which were made by John Aitken of Falkirk. His experiments were made before the discovery of the electron, and had no direct connection with it, but his method of experiment was adopted by C. T. R. Wilson in the Cavendish Laboratory, in connection with the electron.

Aitken's work, *On Dust, Fogs and Clouds,* was published in 1880, and the part which interests us most is his ingenious method of counting the invisible dust particles which exist in ordinary air. He set himself such questions as this: "Why should the water vapour condense out of the air in one case in particles so minute that they seem to have no weight, and remain suspended in the air as clouds, or fogs or mists, while in another case they are large grained, and fall rapidly in rain?" In order to answer this question, Aitken devised the following experiment.

He took two large glass receivers, both connected to a boiler by means of pipes. When he allowed steam to pass into the first receiver, it soon filled with a dense, foggy cloud. On admitting a similar quantity of steam to the second receiver, there was no cloud formed; the steam remained invisible. Why this difference?

The first receiver, before the experiment, was filled with ordinary air from the room, whereas the second receiver was filled with dust-free air; all dust had been removed by passing the air through a filter of cotton-wool. The real difference between the two receivers was that there was dust in one, while there was little in the other; all other conditions were similar. But why should dust have this peculiar action? Or put another way, Why does not the water vapour condense into a cloud in air free from dust? In both cases the air is supersaturated, and yet

in the dust-free vessel the water refuses to condense in the air.

In his explanation, Aitken pointed out that we know water will pass into vapour if heated above boiling-point (100° C. at standard pressure). Also that water will pass from vapour to liquid if cooled below 100° C., and that something more than mere temperature is required to bring about these changes. Before the change can take place a "free surface" must be present, and at this the change takes place. A free surface is a surface at which the water is free to change its condition. For instance, the surface of a piece of ice in water is a "free surface," at which the ice may change to water, or the water change to ice. Again, a surface of water bounded by its own vapour is a "free surface," at which the water may vaporise or vapour condense. The freezing- and boiling-points of water are the temperatures at which these changes take place at such "free surfaces."

It is well known that water may be cooled, in the absence of "free surfaces," far below freezing-point without becoming solid ice, and, on the other hand, the temperature of ice has been increased above freezing-point without melting, in the absence of "free surface."

From these facts, Aitken showed that it requires a lower temperature to cause a molecule of water to adhere to another molecule of water (to form ice), than for a molecule of water to adhere to a molecule of ice. Also that it requires

a much higher temperature to cause a molecule of water, surrounded on every side by other water molecules, to pass into vapour, than for a water molecule, bounded on one side by a gas or vapour molecule, to pass into a state of vapour. Aitken gave these particulars in explaining the difference in condensation in the receivers already described. Before the water could condense there had to be a free surface, otherwise molecules of vapour could not combine with each other to form a particle of fog or mist. That explained why there was no condensation in the dust-free air, while a cloud was formed in the other receiver, by the vapour condensing on the dust particles suspended in the air, these forming "free surfaces" at which condensation was able to take place. Where there is abundance of dust, there is abundance of "free surfaces," and the visible condensed vapour forms a dense cloud, but where there is no dust to form free surfaces, no vapour is condensed into a visible form; it remains in a supersaturated vapour condition till the circulation of the air brings it into contact with the "free surface" formed by the sides of the receiver, in which it becomes condensed.

Each fog or cloud particle in the experiment is built upon a dust particle. This indicates the presence of an enormous number of dust particles in the air. It is not necessary to suppose that all the dust particles were used up as nuclei of fog particles; these might form only a small part of the total dust particles present, and Aitken

sought to prove this statement in the following manner:

He sent, into a receiver, sufficient steam to form a dense cloud. He then allowed the fog to settle, but he did not allow any more dust to enter. After the fog had settled, carrying its dust particles with it, more steam was admitted, and again a dense fog was obtained. The dust forming the nuclei in this second cloud had escaped vapour being condensing upon them in the previous experiment. He then allowed this second cloud to settle, thus depriving the air of some further dust particles, and he repeated this process a number of times. After many repetitions, fog still formed, but after each condensation the fog became less and less dense, and finally disappeared as fog, but on looking closely into the receiver a fine rain was seen to be falling within it. The fog required more dust particles than the rain.

Aitken pointed out that if there were no dust particles in the atmosphere there could be no fogs, clouds or mists, but every blade of grass and every branch of tree would drip with moisture deposited by the dust-free air, our dresses would become wet and dripping, and umbrellas useless; but our miseries would not end there. The inside of our houses would become wet; walls and every object in the rooms would be soaked with moisture.

We must remember that the dust particles which save us all this misery of dampness are

invisible even in a microscope. How, then, did Aitken succeed in counting them ?

He devised another experiment which dispensed with the steam ; he found that when the

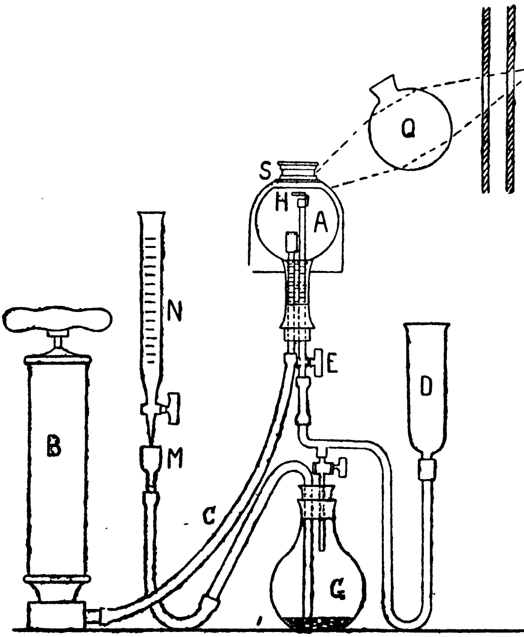


FIG. 20.—AITKEN'S CLOUD APPARATUS.
Showing the apparatus with which Aitken counted the dust particles in air.

air was cooled by suddenly expanding by withdrawing part of the air with an air-pump, the condensation and cloud formation took place. Here is the arrangement of his apparatus, and it was this method which proved useful to C. T. R. Wilson (Fig. 20).

A is the test receiver into which the air under investigation is introduced.

B is the air-pump for withdrawing some of the air to cause condensation.

C is a rubber tube through which the air is drawn.

D contains cotton-wool through which the air is pumped into the receiver *A*, thus freeing it of dust.

G is a flask into which the air is introduced before entering the test receiver *A*.

It will be noticed that *A* contains water so that the air may be saturated with water vapour.

H is a small mirror on which the fog particles may fall, and it is divided into squares of definite measurements, so that the drops may be counted in an area of known dimensions. The mirror is viewed through a compound magnifying glass *S*.

The stage was lighted by means of a gas flame *R*, the light of which is focused by the globe of water, *Q* acting as a lens.

If a large quantity of ordinary air were tested, the mirror would be so covered with water drops that it would be impossible to distinguish them individually. To overcome this difficulty only a very small quantity of the air to be tested is mixed with the dust-free air, and in this way a definite dilution is arrived at, and the drops may be counted. Then a calculation of the total quantity in the air may be made from this known dilution.

The operation of the apparatus is as follows:

The first thing is to fill the receiver with dust-free air and make it ready to receive the addition of a small quantity of the air to be tested. The receiver *A* is soon filled with dust-free air by working the pump *B*, and drawing the air through the filter *D*. The stop-cock *H* is closed to cut off the air which is to be tested.

Before the air is purified of dust we may close the stop-cock *E* and make another stroke with the pump, thus expansion of the air causes condensation. The density of the cloud thus formed will depend on how much of the dust we have withdrawn. Ultimately we reach a point at which no condensation takes place. When the air is nearly pure there are large drops formed, and these soon settle down, some falling upon the little mirror. This happens also after we have pumped the air and admitted the small quantity of air to be tested.

Aitken counted the drops and calculated the number of dust particles which would exist per cubic centimetre of the undiluted air.

The parts of the apparatus marked *M* and *N* are for measuring the quantity of air which is to be tested.

We have seen that air saturated with water vapour, if suddenly chilled, will cause the surplus of water (*over and above that which would saturate the air at the lower temperature*) to condense in little particles of water and forms a mist or a cloud. We have seen also that there must be a nucleus around which the water may gather. In Aitken's

experiments we have seen that the nuclei were invisible dust particles, and that no cloud would form in the absence of these.

C. T. R. Wilson's work depends upon the fact that a gas is an almost perfect insulator, but that under the influence of X-rays, or radium radiations, it becomes a conductor. This change is due to rays robbing the molecules and atoms of electrons. An electron is shot off, leaving the remainder of the molecule or atom with a positive charge. The electron which has been set free soon attracts to itself one or more atoms. We may picture a mixture of small groups of atoms moving under the influence of an electric field, just as the wandering atoms or ions do in a liquid. If these gaseous ions are left to themselves they soon recombine to form neutral molecules. If we wish them to remain, we must keep bombarding them with X-rays or radium radiations.

C. T. R. Wilson tried to use these gaseous ions as nuclei in Aitken's experiment, and he succeeded. Drops of water condensed on both the negative ions and the positive ones, but the amount of supersaturation necessary was less for the negative electrons, while it required to be greater before the condensation took place on the positive ions.

Wilson found that when the supersaturation was correct, each negative ion behaved just like Aitken's invisible dust particles, and that each became the centre of a single drop of water. These drops were all of the same size if the

conditions were uniform. A single drop is invisible, but a crowd of them forms a visible cloud. This myriad of drops will gradually fall by gravity, just as we see a cloud attracted by a mountain-top. The rate of fall is very slow if the drops are very small; indeed, clouds appear to float in the air, which is not really the case—they are always falling, though the rate may be ever so small.

H. A. Wilson watched the cloud in his apparatus and took note of the rate of fall, and from this he was able to calculate the size of a single drop. He then put a brake upon the fall of the cloud by applying an electric field. This he did by placing a negatively charged plate beneath and a positively charged plate above the cloud. He adjusted this brake so that the cloud was held steady; the fall was balanced by the electric field. In this way the charge on the drop was calculated, and it was found to be the same as Thomson had calculated, as the charge of an electron in his vacuum-tube experiment already described.

C. T. R. Wilson's apparatus is shown in diagram, Fig. 21.

The lower part of the apparatus represents the means of producing a vacuum. The tube *T* is connected to an air-pump, and by means of this a partial vacuum is produced in the vessel *V*. The rubber-stop *S* cuts off the connection with the air-pump, until the stop is withdrawn by the rod *R*.

It will be observed that a light glass vessel *F* floats inside the larger vessel *V*, in which is some water. As soon as the partial vacuum takes place in this floating chamber it falls. Indeed, it is forced down with great rapidity. This produces a sudden expansion of the air in the larger vessel *V*, which is connected to the experimental chamber *E*. This is where the cloud is to be formed between the two electrified plates *P* (positive plate) and *N* (negative plate).

In making the experiment it is necessary to get the air free of all Aitken's dust particles, and this is done, as he did, by repeated expansions, causing each cloud formed to carry down dust particles until the air is left dust free.

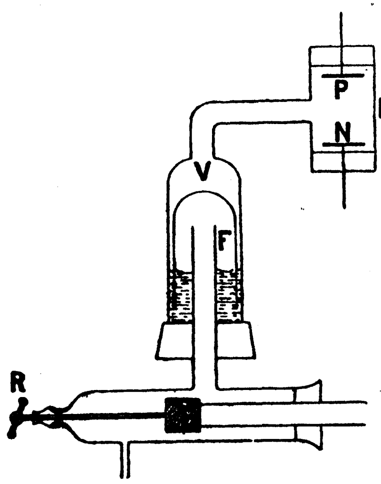


FIG. 21.—WILSON'S CLOUD APPARATUS.
Apparatus by which those tracks of Alpha particles are seen.

In order to have a myriad of negative ions in the experimental chamber, it is convenient to bombard the plate *N* with ultra-violet light to free electrons from the plate, as will be explained in a later chapter; thus electrons are freed in a sufficient quantity. These free electrons escape

from a zinc surface very freely when bombarded with the short waves of ultra-violet light, as we shall see later. The plate N is usually made of zinc. Alternatively, X-rays may be used to produce negative ions (the atom's stable number of electrons being upset by the impact). The experimental chamber having been filled with negative ions, or with free electrons, as the case may be, the cloud is formed by expanding the supersaturated air. A note is taken of the rate at which the cloud falls, and then the opposing electric field is applied until the cloud becomes stationary, and the amount of charge is calculated.

Another form of this experiment was devised by R. A. Millikan. He vapourised or "atomised" oil, and sometimes mercury, using these in place of the water. The advantage in this was that these substances did not evaporate appreciably, and it was possible to view a single drop through a microscope. The eye-piece of the microscope contained an engraved scale, on which the whole of the measurements of the motion of the drop could be made very accurately. By the adjustment of the electrification of the plates P and N, the drop could be suspended in the air, and kept in view in the microscope for any desired time. The calculation of the charge in the case of the oil and of mercury were found to be identical with the charge of a single electron.

In Millikan's experiment, the gas was, of course, ionised as in Wilson's experiment, either

by X-rays or by radium radiations. Sometimes the ionised drop, when poised in the air, would suddenly make a dart towards the positive plate (*P*). This showed that the drop had captured another negative charge, and so the electric balance was upset. On other occasions the drop would be seen to fall down upon the negative

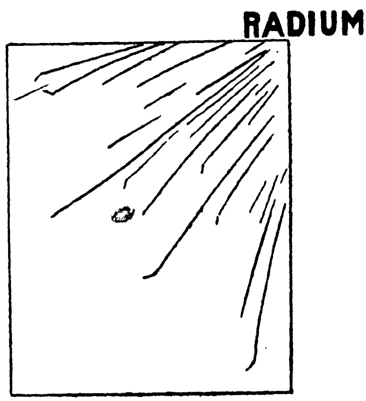


FIG. 22.—TRACKS OF ALPHA PARTICLES.

Alpha particles are expelled by the exploding atoms of radium. They course the air and provide nuclei for condensation, hence the track is made visible.

plate (*N*), showing that it had parted with an electron to some colliding molecule, and again the electric balance was upset, and this time in the opposite direction; the drop being left with a surplus of positive electricity is attracted towards the negative plate.

There was a difference between Millikan's and H. A. Wilson's experiments. The drop of oil or mercury could collect more than one charge of

electricity, but this could exist only in definite multiples of the charge in a single electron ; in other words, the drops could carry more than one free electron.

It is very interesting to watch a stream of radium radiations forming one of these clouds. The Alpha particles, which we know to be helium atoms, are shot across the experimental chamber, and as a particle passes it ionises the air, thus leaving behind it a trail of cloud when the air is expanded. The waterdrops form in the ionised air, and produce tracks as shown in Fig. 22.

Each of these lines represents the track of a single Alpha particle. A small piece of apparatus has been devised for demonstrating these tracks, and it makes a very interesting experiment.

CHAPTER VI

THE POSITIVE PARTICLE

WE knew about the electron for some time before we had any knowledge of the particle of positive electricity. Our present knowledge came about

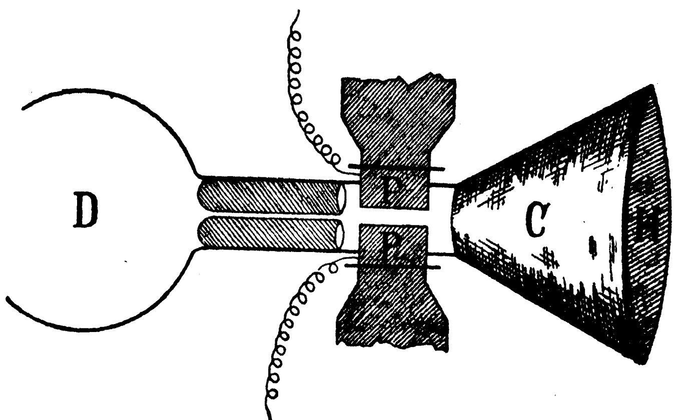


FIG. 23.—APPARATUS FOR POSITIVE RAYS.

A stream of electrons is produced in the discharge tube *D*. The electrons pass through *D* from right to left, while the positively charged particles pass through in the opposite direction, passing through the hole in the cathode, seen between *D* and *P P*. They then pass between *P* and *P* and enter the chamber *C*.

through Sir J. J. Thomson's work on the positive rays. These rays were produced in the following manner (Fig. 23):

D represents the discharge tube, which pro-

duces a stream of electrons. It is well known that some particles of air remain in the vacuum tube, and that they are *ionised* by the bombardment of the electrons. The positively charged ions are attracted to the negative electrode (Cathode), and in this way there is produced a stream of positive rays, travelling, of course, in the opposite direction to the negative stream of electrons. The positive stream is composed of positively charged atoms.

How can we get the stream of positive particles separated from the stream of negative particles? This is done by perforating the cathode, so that the positive particles may pass through and emerge on the other side, and this they do with unimpaired velocity. They may show their presence by bombarding a phosphorescent screen, or they may register their presence by bombarding a photographic plate. The screen is covered with a powdered mineral called willemite, which becomes phosphorescent when bombarded by the rays. The rays of positive particles pass through the tube connecting the discharge tube *D* with the chamber *C*, in which the phosphorescent screen is placed, at the end of the tube. The photographic plate, if used, would be placed in the same position. The chamber *C* is connected by a small tube (not shown in diagram) to a tube containing charcoal, and this tube is immersed in liquid air during the time the experiment is being made. Sir James Dewar had discovered that if charcoal was cooled to the low temperature of

liquid air (190° C. below zero) the charcoal became exceedingly absorbent of any gas which was present. Therefore, by the presence of this chilled charcoal, the chamber *C* is cleared of residual gases, and its pressure is even lower than that of the discharge tube. In this way the space within *C* is cleared of all possible atoms which might be obstacles to the pencil of positive particles.

This pencil passes between two iron blocks, *PP*, which are let into the sides of the connecting tube. These are made of soft iron, as they are to act as the poles of an electro-magnet. The ends of these blocks are insulated from the main body of the magnet by means of a sheet of mica. The reason for the insulation is that these ends are to act also as electrified plates, positive and negative respectively. By this arrangement both a magnetic and an electric field may be applied to the pencil of positive rays.

It will be observed that the two fields are placed parallel to one another, whereas, in the tube used for the measurement of the electron, the two fields were placed at right angles to one another.

In the positive ray tube the pencil of rays will be deflected at right angles by the two fields.

One field will tend to send the pencil in one direction, while the other field will tend to place the pencil in a direction at right angles; and the result will be that the pencil will form a curve

or parabolic line, provided the two fields are acting at one time. The pencil will be bent round in a parabola, as shown in the diagram (Fig. 24).

The positive particles are formed by robbing atoms of electrons, and this will take place in

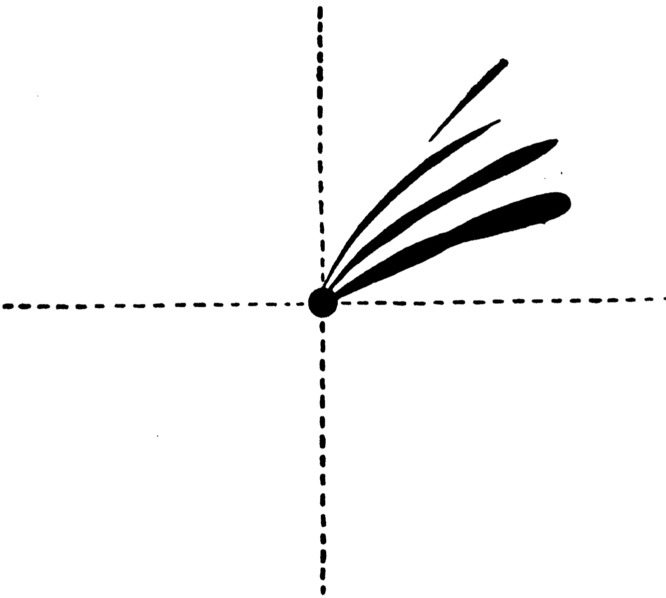


FIG. 24.—PARABOLAS.
Positive rays deflected by magnetic and electric fields.

different parts of the tubes. If some of these particles are created near to the positive electrode they will acquire a greater velocity than those formed nearer the negative electrode. Hence the stream or pencil will be composed of particles flying with different velocities, and

these will be influenced differently by the magnetic and electric fields, according to the velocity of the particles. They spread the pencil into a sort of band, the particles being placed in different positions.

The electric pressure which urges these flying particles in the discharge tube is between 30,000 and 40,000 volts.

The position of a particle in the parabola will depend also upon the length of time it remains positively charged. On its journey it may pick up an electron and become neutral, when it will no longer be influenced by the applied field. The electric field is produced by a battery of small accumulators.

The positions of the positive particles will depend also on the mass of the particle itself, and as these are atoms of matter they will vary in atomic weight according to the elements forming the gas which filled the tube before exhaustion. It is possible to detect the elements present by their atomic weight, which may be calculated from the parabola produced by Hydrogen.

The amount of an element which can be detected in this way is exceedingly small, far smaller than that detected by a spectroscope.

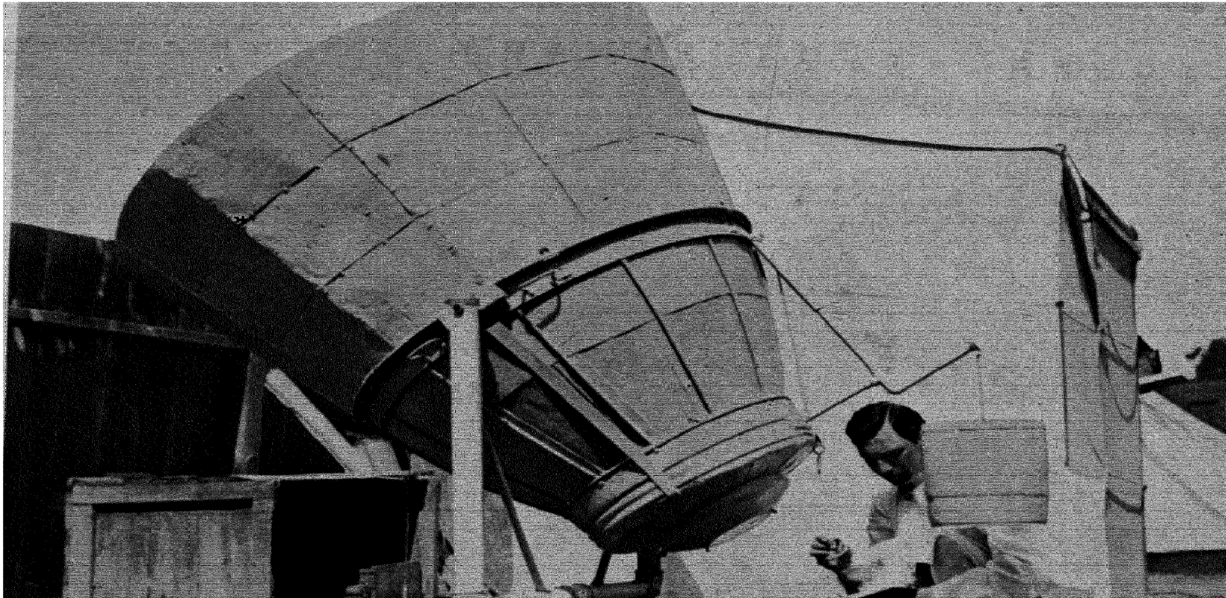
The spectroscope will detect the small amount of sodium present in a speck of common salt when placed in a bunsen flame. It will even detect a single drop of blood in a teacupful of water, even the difference between the blood drawn from

an artery may be distinguished from that drawn from a vein. The distinction is due to the presence of oxygen in the arterial blood. The positive ray apparatus can detect even smaller quantities of an element present in a gas. It is well known that helium is a rare gas; indeed, it was discovered in the Sun before it was known to exist on the Earth. There is a very, very minute quantity of it present in the air, so small that you would think it impossible to detect it unless we considered an enormous volume of air. Yet one single cubic centimetre of air contains sufficient helium to be detected by the photographic effect.

Sir William Ramsay has calculated that the helium present will fill a space no more than four millionths of a cubic centimetre.

The velocity of the positive particles within the discharge tube is somewhere about 600 miles per second, which is 36,000 times greater than the speed of an express train.

As the particles would cover a mile in one six-hundredth part of a second (if they could travel so far), they will cover the distance from the discharge tube to the photographic plate in less than one millionth part of a second. This is all the time given for the taking of the photograph, which we may describe rightly as an instantaneous photograph.



Sport and General

UTILIZING THE SUN'S HEAT RAYS

This is another view of the machine shown in the illustration facing page 72. The heat produced is sufficient to melt a diamond, while carbon is easily liquefied. The inventor believes he will be able by further experiment to reach a temperature of 30,000 degrees Fahrenheit; he has already attained 15,000 degrees.

The Positive Particle

MEASURING THE BETA RAYS OF RADIUM

It is well known that the rays given off by radium consist of:

(1) Positively electrified atoms of helium, which have been robbed of electrons. These are the well-known *Alpha rays*, or particles, and they are shot off with great velocity. We shall see later an experimental use to which we put these flying particles.

(2) Free electrons, which are flung off by the radium with great velocity. These are electrons which have escaped from exploded radium atoms, and they go by the name of *Beta rays*, or particles. We shall see in the next experiment how their mass is determined.

(3) Ether waves, which are X-rays of higher frequency than we can produce in the laboratory. These are known as *Gamma rays*.

Professor Kaufmann has devised a means of measuring the mass of the Beta particles emitted by radium.

The mass of an electron increases with the velocity at which it is moving, and in the Beta rays the electrons are moving with a velocity within 4 per cent. of the velocity of light, at which speed the mass of the electron should be greatly

increased. Kaufmann succeeded in measuring the mass. The arrangement of his apparatus is shown in Fig. 25.

The radium, which is merely a very minute quantity of radium salts, is placed at *X*. It is shooting off Beta particles (electrons), and these pass through a hole in a lead screen (*L* in diagram), and strike a photographic plate (*P*).

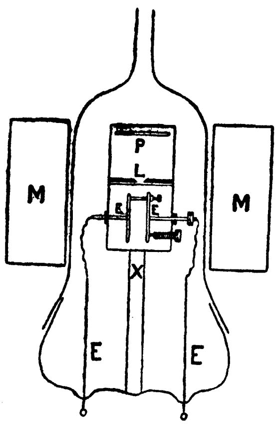


FIG. 25.—APPARATUS FOR BETA PARTICLES.

A minute quantity of radium salts is placed at *X*. Electrons are shot through a hole in the lead screen *L*, and strikes a photographic plate *P*. The mass of the flying electrons is measured by this apparatus.

On their going from *X* to *P* the electrons pass through an electric field produced by the plates *EE*.

A magnetic field is obtained by placing the whole apparatus between the poles of an electro-magnet (*M*). The beam of electrons is deflected by the fields as in the previous experiment, and the mass of the electrons was shown to depend upon the velocity when that is very high.

The results obtained by Kaufmann agreed with the theoretical values calculated of the mass, which at the high velocity was found to be about three times greater than that of an electron moving under more ordinary electric pressures in

the laboratory. In Radioactive changes, the velocity produced is much higher.

Referring to the construction of matter, we might consider a different type of experiment, which has been used merely as an analogy, and which explains the arrangement of the electrons within the atom.

The experiment was invented by Mayer. A

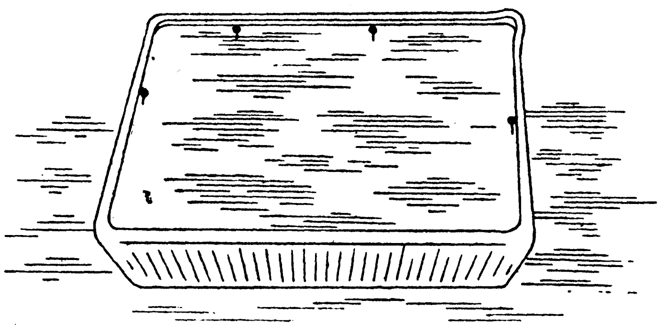


FIG. 26.—FOUR FLOATINGS (FREE).

Similar poles being uppermost repel one another and drive the corks to the sides of the basin.

large number of needles are magnetised by placing them together in the magnetic field produced by a solenoid, in which an electric current is passing. Each needle is placed in a cork, and all are floated in a basin of water. The needles hang down in the water vertically, having, say, all their north poles uppermost. The result is that all the north poles will repel one another, and the needles will take up positions as shown in Fig. 26.

This represents what would take place in the case of electrons unless there was some balancing force, such as the positive nucleus.

The balancing force is represented in Mayer's experiment by the south pole of a magnet, which will attract the north poles of the floating magnets,

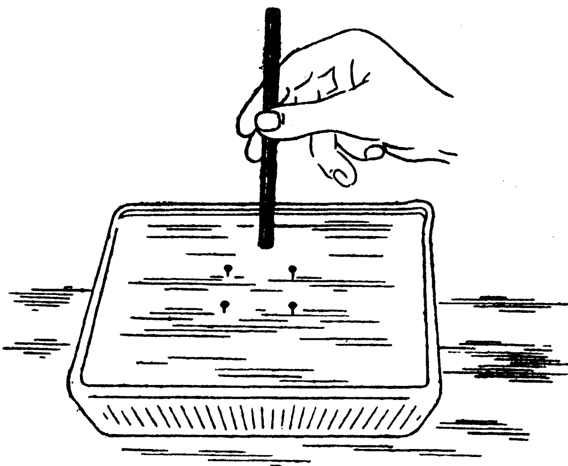


FIG. 27.—FOUR FLOATING MAGNETS (CONTROLLED).

The south pole of a permanent magnet is held over the basin, and in this way the floating magnet north poles are attracted. They always form a square.

and bring them nearer to one another, till the attractive and repulsive forces are balanced.

A permanent magnet may be held above the floating magnets, or an electro-magnet may be placed beneath the basin, to represent the nucleus.

If the magnet is placed beneath the basin, it will act upon the south poles of the needles, as these are nearer the bottom of the basin, hence

we must apply the north pole of the electro-magnet. If we place four floating magnets in the basin, they will take up positions forming a square, as in Fig. 27.

If we add other three magnets, making seven in all, they will arrange themselves as in Fig. 28,

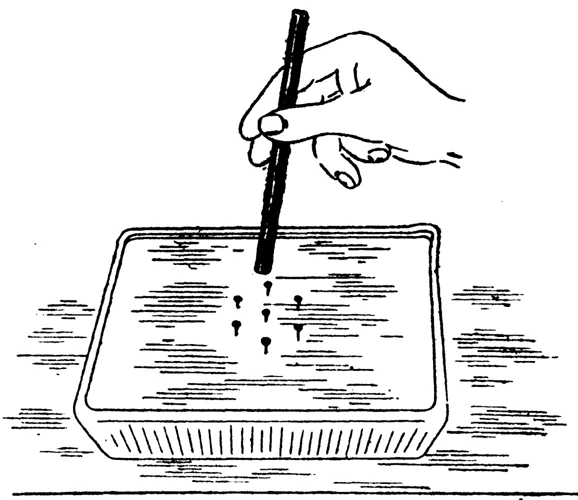


FIG. 28.—SEVEN FLOATING MAGNETS.
Under the influence of the neighbouring magnet the seven floating magnets form a ring of six and one magnet at the centre.

one of the magnets going to the centre and the other six forming a ring outside.

Ten magnets will arrange themselves in a ring of three and a ring of seven outside.

If we increase the number of magnets to eighteen, we get the figure shown in Fig. 29.

Here we have one magnet in the centre, then a ring of six, with a large ring of eleven outside.

The results of the experiments show that the greatest number of magnets we can have forming an empty ring is five. When we add another magnet it goes to the centre. We have seen in Fig. 29 that an outer ring of eleven has seven in the centre.

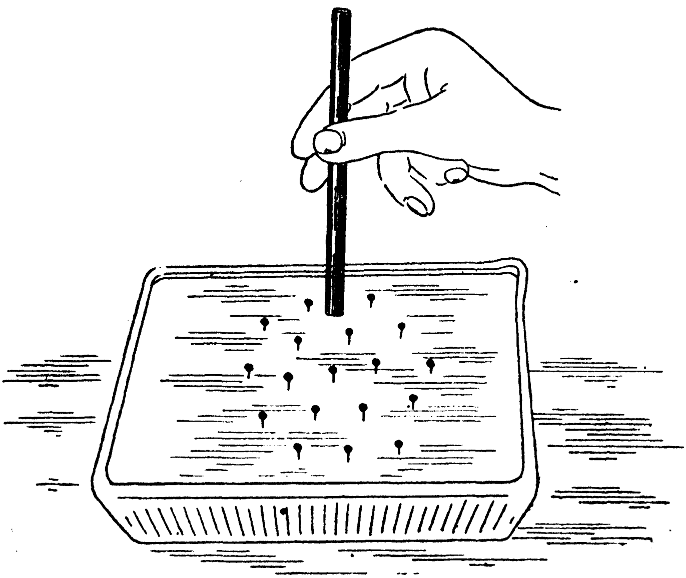


FIG. 29.—EIGHTEEN FLOATING MAGNETS.

Eighteen magnets take up their positions as follows: One in centre, a ring of six, with an outside ring of eleven.

If we increase the outer ring to thirty magnets, we require to have 101 magnets in the centre to balance matters.

These configurations give us mental pictures of the possible arrangement of the electrons in the atoms.

The experiment may be varied: groups of magnets may be formed by magnetised steel spheres, which will float in a basin of mercury; the light reflected by the spheres may be focussed on a lantern screen. The little spherical magnets may be added one at a time on the surface of the mercury, and it is interesting to see the different formations take place on the lantern screen. For a lantern demonstration, it is more convenient to use an electro-magnet beneath the basin of mercury.

Photo-Electricity

Reverting to the subject of electrons themselves, the reader may be interested in a brief description of Photo-Electricity.

We have become familiar with the idea of detachable electrons, which may be transferred from one object to another, producing the phenomena of electrified bodies. We know also that electrons are discharged from the incandescent filament in a thermionic valve as used in wireless telephony.

We shall see that some of these detachable electrons have so little anchorage that they may be dislodged by the impact of ether waves composing light. In 1887, Hertz found that the passage of an electric spark was made more easily when another spark passed in the neighbourhood, and he showed that the effect was due to ultraviolet light from the neighbouring spark falling

on the gap in which the other spark was produced. This discovery was made at a time when we knew nothing about electrons, which were discovered ten years later.

Following on Hertz's discovery, Hallwachs discovered, in the succeeding year, that if a metal plate were charged with negative electricity, it tended to lose its charge when ultra-violet light was caused to fall upon the plate.

A simple demonstration of this phenomenon may be given by charging (with negative electricity) a polished zinc plate, connected to an electroscope, and then allowing the light of an arc lamp to fall upon the plate, the arc light being rich in ultra-violet rays. If we charge the zinc plate with positive electricity, which is another way of saying if we subtract electrons from the zinc plate, no appreciable effect is produced, but when the plate is charged negatively, that is, when it has a surplus of electrons crowded on to it, the electroscope indicates a discharge as soon as the light falls upon the plate.

If we place a sheet of ordinary glass between the source of light and the zinc plate, we cut off the ultra-violet light, so that it fails to stimulate the surface of the plate, and there is no discharge of the electroscope.

By suitable methods of experimenting, it is possible to measure the maximum velocity of the electrons escaping from the metal. The results of such experiments show that the ejection is produced quite independently of temperature,

and it is due to absorption of radiation energy. If the intensity of the light is increased, there are more electrons liberated, but their velocity is not increased by the increase of intensity.

It is well known by all that when light falls upon a photographic plate it brings about a chemical change in the prepared surface, and a natural question is to ask if this liberation of electrons by light has anything to do with the production of a photograph.

We know that a transference of electrons from one set of atoms to another brings about the chemical union of atoms into molecules. We may picture the atoms composing the molecule as being held together by the presence of these *valency* electrons; we used to picture bonds linking the atoms together before we knew anything about electrons.

In the case of light falling upon a photographic plate, the impinging of the ether waves disturbs the electrons and brings about a chemical change.

CHAPTER VII

THE ELEMENT RADIUM

THOSE of us who remember the discovery of radium no doubt think of it as a recent event, but it is now a generation old, so it may be of interest to recall the circumstances of the discovery and the impression made upon the minds of the public at that time.

At first it was predicted that radium was going to revolutionise our everyday life; boilers and fires were to disappear, and all manner of diseases were to be cured by its magic. The man-in-the-street was very much impressed by the price of radium salts; it was three thousand times the price of gold.

The discovery of radium was not accidental; it was being sought for, as will be explained. It was the newly discovered X-rays which set man on the track of radium, for the fact that X-rays produced fluorescence in certain chemical substances led two professors independently to ask if the converse might not be true also; might not a fluorescent substance produce X-rays?

The layman may not be clear about the difference between a fluorescent and a phosphorescent substance. They both become lumin-

ous under the bombardment of ether waves, but a fluorescent body only acts so long as the ether waves of light are impinging upon it. It is because of this property that an X-ray screen receiving invisible light sends out visible light. Again, some substances, such as zinc sulphide, continue to send out light long after the bombardment ceases, whereas an X-ray screen will only remain luminous as long as the rays are bombarding it.

The two professors referred to were Professor Sylvanus P. Thompson, of London, and Professor Henri Becquerel, of Paris, and their idea was that it might be possible for a fluorescent substance to produce X-rays. Each professor worked at this idea on his own account, but through what we might call a chance incident, Becquerel got ahead.

Some time after this, Becquerel had discovered that uranium salts possessed the property of affecting a photographic plate. I can remember seeing his early experiments repeated by two research students in one of our universities, and at that time they seemed rather tame affairs.

At first the uranium salts were exposed to sunlight, while the sensitised plate was protected by a black envelope, but it so happened that on one occasion, when Becquerel was about to make an exposure, the Sun became clouded over, and, thinking it useless to continue without the action of the Sun's rays, he put the prepared plate and salts aside in a drawer to await a more favourable opportunity. They lay there for a week, and then

came an incident which was not accidental; the professor wondered if it were possible that any action had taken place in the dark drawer. He developed the plate, there having been no exposure of the envelope to the Sun, and he was surprised to find the photographic action as good as on previous occasions. It was evident that the Sun's rays were not necessary; the uranium salts were sending forth rays on their own account; a new property of matter had been discovered, and this was named *radioactivity.*

The incident which has just been related of the darkened Sun and the dark drawer is very similar to an incident which led to Daguerre's discovery of his photographic method. He had been making very long exposures, in the camera, of prepared metal plates. The exposure necessary to produce a photographic effect was many hours, and the results were very poor. Then, on one occasion, when he had just commenced an exposure the Sun became darkened, and he put the prepared plate away in a cupboard. On taking it out in the morning in order that he might make further experiment with it, he was greatly surprised to find on it a beautiful picture of the scene he had proposed to photograph on the previous day. The picture was infinitely better than those made by long exposures, so much so that his joy knew no bounds. He shouted, "I have seized the light! I have arrested his flight! The Sun himself in future shall draw my pictures!"

Another short exposure and another night in

the cupboard produced another "perfect picture." Then the vapour of mercury was suspected of being the active agent in developing the picture, and another short exposure and immediate treatment with mercury vapour produced another beautiful picture.

The two incidents—the one of Becquerel and the other of Daguerre—are very similar, both being due to the incidental clouding of the Sun when they were about to experiment.

After discovering that uranium salts were radioactive *per se,* Becquerel made another important discovery. He found that the radioactive salts had the property of rendering the surrounding air an electrical conductor, as was evident by the discharge of any electrified body in the neighbourhood of the salts. This gave an excellent test of a substance being radioactive, and Professor Curie and his wife set about testing different substances as to their respective radioactivity. Among other things, they tested a piece of pitchblende, from which substance the uranium salts are obtained. They found the pitchblende to be more radioactive than was accounted for by the uranium. This was very surprising, and showed the presence of some substance which was much more radioactive than uranium. With great labour and patience the Curies succeeded in extracting a more radioactive substance, to which they gave the name *Polonium,* in honour of Madame Curie's native land of Poland. This substance, however, would not account for the radioactivity of pitch-

blende, so it was evident that there was still some more active substance present in the pitchblende. By further qualitative analysis another radioactive substance was found to be associated with the barium. The barium compound is easily separated with the aid of sulphuric acid, and the white precipitate formed contained a very radioactive substance. This substance was separated by means of fractional crystallisation. The element itself was not isolated, but it was in the form of a bromide compound, and to this very radioactive substance the name of *Radium* was given.

The discovery was remarkable because of the very small quantity of radium present in pitchblende. Indeed, Sir J. J. Thomson has stated that the percentage of all radioactive substances present in pitchblende is less than the amount of gold held in solution in sea-water.

While many tons of pitchblende require to be treated to obtain a very small quantity of radium salts, even a mere speck of these can show wonderful radioactive effects. The radiations may be made visible by allowing them to bombard a screen of zinc sulphide which becomes luminous.

The high price of radium is not due to its rarity, but to the immense cost of isolating it, the resulting cost being very great even for a mere speck—a milligram.

No one who understands the properties of radium has any desire to handle a quantity of it. Its physiological effects are dangerous, as was

discovered in the early days by Becquerel, who happened to carry a small quantity (a few milligrams) in a glass tube in his waistcoat pocket; it produced a sore on the body.

You might mistake a few grains of radium salts for common table salt, excepting that the radium salts are slightly luminous in the dark.

The radioactivity of radium is infectious. Sir William Crookes made many experiments by placing diamonds in contact with radium salts, whereupon the diamonds became radioactive, and incidentally they acquired colours. Our present interest lies in the fact that they become infected with radioactive properties.

Crookes gave an account of his experiment in the *Philosophical Transactions of the Royal Society* (1914), from which the following is a quotation: "A large brilliant-cut diamond of pure water assumed a fine green colour after having been kept for sixteen months in a bottle and covered with powdered radium bromide. At the end of that time it was highly radioactive. This diamond has been carried about in my pocket, off and on since 1905, and has been tested on a sensitive photographic film at intervals of a year or more. No appreciable difference in its radioactivity can be detected from that which it possessed when first removed from the radium bromide in September 1905. Examined at the present time, nine years after its removal from the bottle of radium bromide, it is luminous in the dark, it rapidly discharges a sensitive electroscope when held near

it and produces scintillations on a zinc sulphide screen as if it were a radium compound."

There is another fact which proves that a radium compound is a source of energy; the radium salts are giving out heat, and that is evident by the temperature, which stands several degrees above that of the surrounding atmosphere.

While all experiments are made with compounds of radium, the metallic element was successfully separated by Madame Curie and M. Debierne in 1910. It is a white metal and dissolves in water, producing hydrogen gas; it combines with the oxygen of the water and sets the hydrogen free.

Of course, the quantity of the element radium which was obtained was exceedingly minute, but its melting-point was discovered and was found to be 790° Centigrade.

While it was found, as already stated, that there was a substance (polonium) in pitchblende two and a half times more radioactive than uranium salts, the actual difference between the radioactivity of the element radium and the element uranium is enormous; the activity of radium is said to be two million times that of uranium.

Its atomic weight has also been discovered, and a very full account of the matter is given in the *Proceedings of the Royal Society* (1912).

Madame Curie calculated the atomic weight to be 225, and later as 226, and, still later, Sir

William Ramsay gave the atomic weight as 226·36.

In some experiments for determining the atomic weight of radium, Sir Edward Thorpe required to use half a ton of pitchblende residues, from which were got 413 grammes of mixed chlorides of barium and radium. No less than 9400 recrystallisations were carried out. It will be understood that the quantities to be weighed were extremely small, and it was found that for weighing these a special balance had to be constructed.

The radiations of radium were found to be complex, but they were separated into three classes, to which the three first letters of the Greek alphabet were given to describe them. It is worth while relating these again.

The Alpha rays were found to be atoms of matter which were discovered later to be atoms of the element helium, which is one of the inert gases. It derived its name from the fact that it was first discovered in the Sun (Greek, *Helios*). This discovery was made by Sir Norman Lockyer in 1868, and for a long time it was considered to be confined to the Sun and other stars. It was not discovered on the Earth till 1895, when Sir William Ramsay made the discovery while examining, by means of the spectroscope, the gases obtained by boiling the mineral clevite with dilute sulphuric acid. While this discovery was made by the spectroscope, it was discovered later, when the gas helium was produced in some

quantity, that it was exceedingly light, coming next to hydrogen in the matter of atomic weight. It has been used for filling the balloons of airships, its chief advantage being that it is non-inflammable. However, hydrogen has the advantage of being much more easily obtained.

The atoms of helium which are shot off by the exploding radium atoms are positively charged, showing that they are short of electrons; but they can soon pick up electrons when passing through the air, and indeed there is a stream of electrons shot off by the exploding radium atoms, and these electrons form the so-called *Beta rays*.

The third, or *Gamma rays*, are X-rays of high frequency, a higher frequency that we can produce by X-ray tubes in the laboratory.

It is fortunate that all the atoms of radium do not explode simultaneously; the process is a very gradual one. In one million billion of atoms only one atom explodes per second.

The fact that the atoms of helium are expelled with great force has been made use of by Sir Ernest Rutherford, as we shall see in the succeeding chapter.

It was quite a long time before the Alpha rays were discovered to be atoms of helium, though it had been known for some time that they were atoms, or at least particles of matter, and also that they were charged with electricity, and that they were ejected with great velocity. It was the fact that helium was found in association with the minerals from which radium was extracted that

led Professors Rutherford and Soddy to suggest that the helium thus found might be due to the disintegration of radium and other radioactive elements. Later experiment brought further knowledge; Sir William Ramsay and Professor Soddy dissolved some radium bromide in water, and, through time, oxygen and hydrogen were set free. Along with these gases there was found some helium gas which could not have come from the water, and therefore must have come from the radium compound.

In a later experiment they found that helium was expelled from radium bromide when heated in a vacuous tube.

It soon became evident that the Alpha rays or particles were helium atoms, which carried away a positive charge, or, in other words, were suffering from a shortage of electrons.

Mention has been made of the property of radioactive substances in discharging electrified objects, and it may be of interest to consider the means of measuring this. In Fig. 30 we see the general principle of an electroscope for this purpose, as arranged by Sir Ernest Rutherford.

The radioactive substance which is to be tested is placed on a table, which is a metal plate connected electrically to earth. The radiation from the substance discharges the plate, which has been charged previously. The plate is connected to the rod, from which is suspended the gold leaf. As the containing case is made of brass, it is necessary to have the rod insulated,

and this is accomplished by supporting it in a plug of sulphur.

The position of the gold leaf is viewed through a glass window, and the rate of discharge is observed by means of a telescope, due allowance being made for the natural leak through the surrounding air. The average rate of movement per minute is directly proportional to the ionisation current between parallel plates, which is dependent upon the intensity of the radiation from the radioactive substance under test.

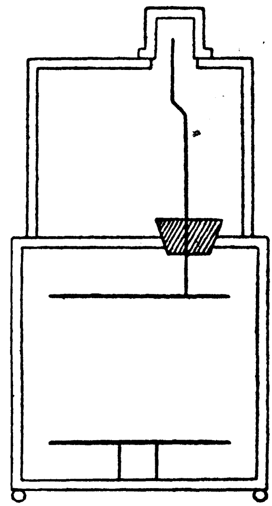


FIG. 30.—RUTHERFORD'S ELECTROSCOPE.

This electroscope is for measuring the discharge of electricity due to the presence of Radium.

The present Lord Rayleigh invented what is known as Strutts Radium Clock, of which a diagram is shown in Fig. 31.

The clock is, in point of fact, an electroscope in a vacuum. The glass tube is evacuated as completely as possible by means of a mercury pump, and the lower part of the tube is lined with tinfoil (*A*), which is connected to earth by the wire *E*. There are two gold leaves (*BB*) which are electrified by means of the Beta rays, which, as already stated, are streams of electrons expelled by the radium salts enclosed in the tube.

While the gold leaves are being gradually charged positively by a loss of electrons, they repel one another. This repulsion of like electricities carries them so far apart that they touch the tinfoil lining of the tube, and thus the charge finds a path to earth, and the gold leaves are brought to a neutral state of electrification so that they fall back to zero, whereupon another accumulation of electrons commences, and the leaves again move towards the tinfoil.

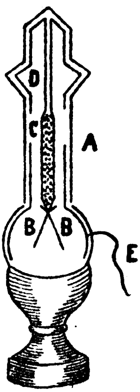


FIG. 31.—RADIUM CLOCK. The gold leaves *BB* are charged by the Radium in tube *C*, and the leaves repel one another until they touch the earth connection *A*, whereupon they are discharged and fall together again, and receive another charge, and so on.

The radium salts are contained in a small tube *C*, suspended from a quartz rod *D*. The radium salts are in metallic contact with the gold leaves.

A full description of the clock is given in the *Philosophical Magazine* (1903), at page 588.

This clock is the nearest mechanical approach we have to perpetual motion, for in two thousand years only one-half of the radium salts would have disappeared, and only one-half of the remainder would disappear in the next two thousand years—so that had the wise men of the time of Abraham, Isaac and Jacob invented such a clock, it might still be at work, provided the leaves were preserved so long a time.

We believe that the element radium is descended from the element uranium, because the proportion of radium found in a mineral has a constant ratio to the amount of uranium present; the belief is that the radium is due to the disintegration of the uranium.

It might be suggested that this could be proved by experiment, for if we extracted all the radium from a uranium compound, there should be a reappearance of radium due to the disintegration of the uranium, but even had prehistoric men arranged such an experiment there would be no accumulation observable yet; the disintegration process is such a slow one.

The atomic weight naturally decreases with disintegration. The table on next page shows the respective atomic weights and the rate of disintegration. It also shows the kind of rays emitted. This forms a genealogical tree.

The table shows Uranium and its Descendants, and we believe that the final descendant is the non-radioactive element lead, atomic weight 206, which, it will be observed, is not a big step from Radium F (polonium), with atomic weight 210. Indeed, the expulsion of a helium atom (atomic weight 4) gives us the result ($210 - 4 = 206$) for lead.

It will be observed that in the table each descending step is due to the loss of a helium atom, hence each atomic weight is four less than its parent. Thus, 234, 230, 226, 222, 218, 214, 210, 206 (lead).

URANIUM AND ITS DESCENDANTS

Element.	Atomic Weight.	Time of Half Transformation.	Radiation.
Uranium .	234·5	10,000,000 years	Helium atoms.
Uranium Y.	230·5	1·5 days	Electrons.
Uranium X.	230·5	24·6 days	Electrons and X-rays.
Ionium . .	230·5	2 × 1,000,000 years	Helium atoms.
(It will be observed that there has been no reduction in atomic weight where there has been no expulsion of matter (helium atoms).)			
Radium .	226	2000 years	Helium atoms, electrons and X-rays.
Emanation (Niton)	222	3·85 days	Helium atoms.
Radium A .	218	3 minutes	Helium atoms.
(Note the short life.)			
Radium B .	214	26·8 minutes	Electrons and X-rays.
Radium C .	214	19·5 minutes	Helium atoms, electrons and X-rays.
Radium D .	210	1·4 minutes	Electrons.
Radium E .	210	5 days	Electrons and X-rays.
Radium F (Polonium)	210	136 days	Helium atoms.

The chief sources of the raw material for the extraction of the element radium are the mines at Joachimstal (Bohemia) and the mines of Cornwall.

It may not be clear to the layman how there can be a change of element without the loss of a helium atom, but it will be observed that the atomic parents lose electrons, and this alters their chemical valency one unit, without loss of atomic weight. We may say that the mass of the atom resides in its positive electricity, hence, although

the nucleus of the atom is extremely small compared with the already infinitesimal electron, yet the mass of the hydrogen nucleus is 1850 times greater than that of the electron.

If we look at the Periodic Table it will be observed that the radioactive substances occur at the heavy end, or, in other words, that they are the elements with the greatest atomic weight—Radium 225, Thorium 232, Uranium 238—while the elements which form the crust of the earth and the surrounding atmosphere occur at the light end of the table, or, in other words, have small atomic weight; water is composed of elements of atomic weight, 1 and 16. While Uranium is the heaviest element on the Earth, it may be that some heavier elements exist in the heavenly bodies though we have not detected them in any meteorites arriving from space, nor does the spectroscope bring us any such information. Uranium is evidently the limit of complexity possible in the circumstances in which the Earth exists.

CHAPTER VIII

CONCERNING RADIOACTIVITY

THE subject of Radioactivity plays such an important part in giving us an insight into the structure of matter that it demands some further reference.

We have seen that the atom of radium when exploding throws off atoms of matter—(helium), called *Alpha rays,* also particles of negative electricity known as *Beta rays,* or electrons; and, thirdly, Ether waves or X-rays, which we call *Gamma rays.* We have seen also that the radium atom is ultimately transformed into lead. It will be of interest to examine further that transformation step in which the radium product becomes a gas, and which is known as *Radium Emanation.* It was christened *Niton* by Sir William Ramsay.

This emanation gas was discovered in the early days of our knowledge of radium, and its discovery came about in this way. Professor Curie and his wife observed that objects which were situated in the same vessel as radium came to possess the same properties as radium; the properties were infectious. At first the Curies

called it an induced radioactivity, thinking that the radium was able to induce its properties in other inert substances, but in the end it was discovered that a gas was produced by the radium, and this is what we call *Radium Emanation*, or Niton.

Sir Ernest Rutherford examined the emanation of another radioactive element—*Thorium*—and in 1900 it was he who discovered that the so-called induced radioactivity was due to the presence of a gas, which was being continuously evolved by the thorium, and he named it *Thorium Emanation*.

In experimenting with this gas, Rutherford discovered that the gas gradually disappears. It does not escape, but its atoms are actually transformed into atoms of a different element, which is no longer a gas. There is a deposit, which produces an invisible coat, covering the surfaces of all objects placed in the emanation. This explained the infection in the case of radium.

This solid deposit was further transformed into other radioactive solids, and at each transformation rays were thrown off (see Table, page 128). Of course, the quantities of these substances which can be dealt with are extremely small. Indeed, they can only be detected by the electroscope; the spectroscope cannot be brought into play; it is the radiation which gives notice of the presence of the substances.

It was in 1902 that Rutherford and Soddy formulated the *Disintegration Theory*. Up to this

time the physicist had considered the molecule as unalterable except by the chemist, but here Nature was not only breaking up the very atoms themselves; there was an actual transformation of atoms, from heavier elements to lighter ones.

It has been remarked that the radium emanation gradually disappeared, and it was observed that its life was between three and four days.

It is a curious fact that a heavy metal (Radium) which has an atomic weight, 226, is converted into a heavy gas (Radium Emanation, or Niton) having an atomic weight of 222. In the latter case the atoms have no hold upon one another, but swim about with many collisions; it is these collisions which produce the pressure of the gas.

It may be asked, What happens to the matter represented by the difference in atomic weight (226 and 222), and the answer is that it has gone to form the Alpha rays, which, it will be remembered, are composed of positively charged atoms of helium. The difference in atomic weight is 226 (Radium), 222 (Emanation), which gives a difference of four, and the atomic weight of the escaping helium atom is 4.

The great velocity with which these atoms of helium are expelled from the radium atoms may be referred to once more, and indicates energy within the nucleus of the radium atom. We believe the escaping electrons (Beta rays) to be expelled also from the nucleus.

It is true that radium is going to pieces, but

the rate of disintegration is very slow. We have seen the emanation formed, but plenty of the radium remains. It would take 2000 years for one-half of it to disappear, and another 2000 years for one-half of that half to disappear, and so on. But seeing it is impossible to observe over such long periods, how can we tell this? It is determined by observing the decrease in the intensity of the rays. In the case of radium, it may be calculated by counting the number of Alpha particles (helium atoms) escaping in a given time from a certain mass.

It will be seen that radium, though in a state of disintegration, has a very long life; but its longevity is put in the shade by its parent—Uranium—which has a life three million times as long as that of Radium. The disintegration of Uranium is so slow that if we consider one billion atoms, only one of these would explode about every third day. It may be that disintegration is a common property of all matter, but if so, it is quite negligible.

An interesting experiment is the liquefaction of radium emanation. It is more effective if carried out in a dark room. It may seem ridiculous to think of liquefying the emanation seeing it exists in such small quantities, but it must not be supposed that we will be able to pour it from one vessel to another as we can do with liquid air. What happens in the case of the emanation is this: We draw the gas through a long tube made of phosphorescent glass; we watch the slow

passage of the gas along the tube which it causes to phosphoresce as it goes; we see the emanation drawn from a receiver, and we watch it enter a receiver which is made also to phosphoresce. This receiver is placed in a vessel of liquid air so that the intense cold may liquefy the emanation. We do not see the liquid emanation, but we see the luminosity gather at the bottom of the receiver instead of the gas filling the bulb, as would be the case but for the very low temperature.

We may watch such transformations from Radium to emanation, but we cannot hasten or delay the explosion of the radium atoms. When a fly-wheel bursts, the explosion is due to the rapid revolution of its particles, which fail to keep their usual good hold upon one another. In the same way we may suppose the explosion of the radium atoms to be due to the rapid revolution of its constituent electrons within its nucleus. The flying particles of the fly-wheel are a danger because of their high velocity, and we find that the Alpha (helium) and Beta (electrons) particles are flying off with enormous velocities.

The flying Alpha particles have been used by Sir Ernest Rutherford in his attempt (1919) to wilfully disintegrate an atom. He has used these flying atoms as shot to fire at the atom. It is certainly very small shot, but the amount of work it can do is not dependent entirely upon its mass. When using a hammer of small mass we can make it do most work by increasing the velocity of its

strokes as much as possible. What the helium atom is lacking in mass it makes up in velocity, which amounts to as much as 12,000 miles per second.

Not only is the target (atom) very small, but it is a very flimsy structure; the electrons and protons filling the space really do so by their rapid revolutions. There would seem to be little hope of hitting the target, as the shot (Alpha particle of helium) might very easily pass right through the

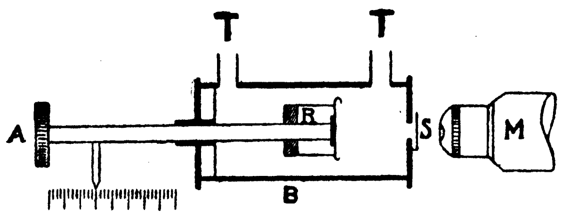
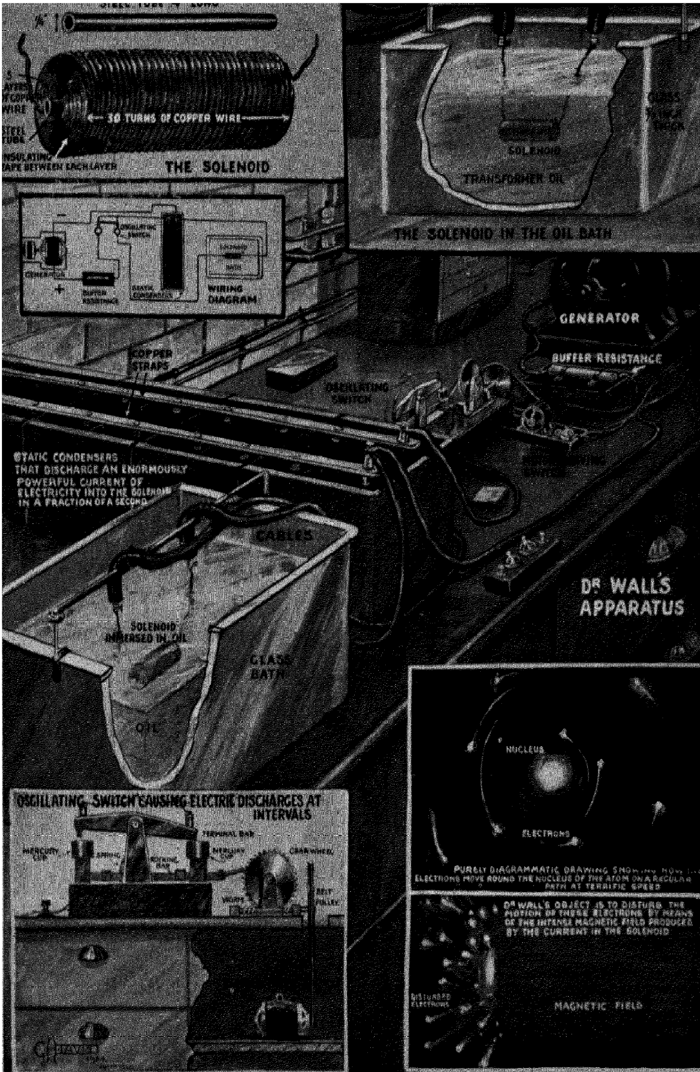


FIG. 32.—SHOOTING WITH ALPHA PARTICLES.
The Alpha particles are shot at the nuclei of atoms, and succeed in hitting some of the targets.

tracery work without doing any damage. One hope of the possibility of making a hit is that there is not only one bullet but a crowd of bullets which spread out, and again the Radium is not firing at a single target but amidst a myriad of targets. It is a regular bombardment, and the targets are the infinitesimal nuclei of the atoms.

The apparatus used by Rutherford is shown in Fig. 32.

B is a brass tube or chamber, which has inlet tubes (*TT*), through which gases may be allowed to pass into the chamber.



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AN ATTEMPT TO BREAK UP THE ATOM

The object of this costly experiment, which was made by Dr. Wall, was to produce an intense magnetic field which would disturb the motion of the electrons which revolve around the nucleus of the atom, and in this way to cause disintegration.

At one end of the tube there is a hole covered with a thin plate of silver, and opposite the hole is a phosphorescent screen (zinc sulphide) marked *S*. This screen is placed very close (1·3 mm.) to the hole, and in the intervening space a screen of mica may be inserted.

The bombarding gun (a speck of radium or thorium salts) is placed at *R*. The range of the gun can be altered by turning the screw *A*, which is attached to a movable rod. The end of the rod may be moved nearer to, or farther from, the phosphorescent screen, which is viewed through the microscope *M*.

The purpose of the screen is to see where the bullets reach; for if they do not travel far enough they will not strike the screen, but are deflected from their path, which will be due to their having collided with atoms on their journey.

There will be electrons (Beta rays) in the chamber, and we must prevent these striking the screen, so the apparatus is placed between the poles of a magnet, and the magnetic field deflects the Beta rays so that they do not strike the screen. When the apparatus is ready, the brass chamber is filled with the gas, which it is proposed to bombard with the Alpha particles. Screens of aluminium or mica of various thicknesses are interposed behind the phosphorescent screen to detect the penetrating power of the particles and the number of scintillations (hits) upon the screen is counted for each thickness.

Rutherford used Hydrogen atoms as the

target, and these are the lightest bodies known: they are lighter than the bullets (Alpha particles) with which they are to be bombarded. The result of this is that, according to Newton's Law, the target (nucleus of the H atom) will travel farther, even more than the bullet (Alpha particle). The lighter the target is the farther may it be projected, if it absorbs all the energy.

Another experimenter (Marsden) had shot Alpha particles through Hydrogen, and been able to detect scintillations on a phosphorescent screen placed at a distance of 80 cm. from the source of the Alpha rays.

The Alpha rays could not travel that distance, their range being 30 cm., so they could not strike the phosphorescent screen. It was evident that it must be the Hydrogen nuclei which were being flung against the screen, owing to collision with the heavy bullets (Alpha particles). Rutherford was able to show that those long range particles did possess the same electric charge as protons (positive particles), and it will be remembered that the nucleus of a Hydrogen atom consists of one of these protons.

These flying particles, which were Hydrogen nuclei, were named H-rays, after the chemical symbol for Hydrogen.

An interesting experiment was made in the following manner. A thin foil of aluminium was bombarded by Alpha particles, in order to dislodge Hydrogen particles from the aluminum atoms. These Hydrogen particles or nuclei are

contained in the nuclei of the aluminium atom. It was found that when the Hydrogen particles escaped they did not all travel in a forward direction, as one would suppose them to do. About as many of them travelled in a backward direction, and others went off in other directions. One possible cause of this might be that the Hydrogen particles were travelling in orbits from which they escaped, and the direction of escape depended upon their position in the orbit when struck by the Alpha particles.

Another interesting observation made was that the Hydrogen particle on escaping from the aluminium foil travelled with a greater velocity than that of the impinging Alpha particle which dislodged it, from the nucleus of the aluminium atom. It seems possible that this increase of velocity may be due to the momentum possessed by the particle in its orbital rotation.

Is it not a remarkable thing that we are able to experiment with individual atoms ?

In other experiments, Rutherford tried bombarding other elementary substances — Boron, Fluorine, Sodium and Phosphorus, and in each case he found these Hydrogen nuclei to be thrown at the screen.

In the course of his experiments he found that he could not dislodge Hydrogen nuclei (protons) from the elements—Carbon, Calcium, Titanium, Manganese, Copper or Tin. He failed with these just as he had done with other elements. It goes without saying that there are protons (H nuclei)

present in the nuclei of all these elements. It so happens that their atomic weights are multiples of the number 4, and as 4 is the atomic weight of the Helium atom, it seems probable that the protons exist in quartettes of 4, or, in other words, in the form of Helium nuclei. This would account for the non-appearance of Hydrogen nuclei, the bombardment being insufficient to dislodge the quartette of four.

It will be remembered that the elements from which Hydrogen nuclei or protons have been dislodged are Boron, Nitrogen, Fluorine, Sodium, Aluminium and Phosphorus, and if you look at the list of elements given on page 36, you will see that these all occur among the lightest elements.

It will be observed further that the intervening elements are the others which Rutherford tried to shatter, but failed. If you look at the atomic weights you will see that each of the numbers of these may be divided by four (leaving the fractions out of account).

Reference was made at page 42 to the suggestion of Prout, which was put forward in 1815. He suggested that all elements were built up of Hydrogen atoms. This suggestion arose from the fact that all atomic weights seemed to be multiples of Hydrogen. It was found later that this was not the case, and so the idea was abandoned for fractional numbers. The reason will be considered in a later chapter dealing with mixed elements.

In Rutherford's bombarding apparatus the

introduction of the mica screen is to determine the range of the flying particles. Each screen has a definite absorbing power, which is equivalent to a known number of centimetres of air. The number of scintillations falls off rapidly as additional mica screens are interposed. If a screen representing a range of 29 centimetres is interposed, then no particles can reach the screen.

It happens that no scintillations occur when the chamber is filled with Oxygen, but the introduction of a little paraffin wax, which is rich in Hydrogen atoms, will quickly show a shower of scintillations. The range in this case is 29 centimetres. When the chamber is filled with Nitrogen the range of H-rays is increased to 40 centimetres; there are different ranges, according to the structure of the atom, or, in other words, according to the atomic weight of the element. The range of 40 centimetres is attained by the disruption of the Hydrogen atom.

The flying protons were deflected from their normally straight path by the influence of a magnetic field. The result is the same as the influence of the field of gravitation produced by the earth and influencing a flying bullet. The faster the bullet is flying the better it can defy the influencing force; the slower the bullet is travelling the greater is the deflection. So it is with the flying protons (Hydrogen nuclei), the greater their velocity the less deflection.

The reader may be anxious to know how many

bullets the experimenter had to fire in order to secure a hit. This is shown by the experiment made by Blackett. He sent Alpha particles (helium atoms) through Nitrogen, using the Wilson cloud apparatus (described at page 94), and he photographed the tracks of the bullets. He counted no less than 300,000 flying Alpha particles, and it was a much easier task to count the deflected particles resulting from collisions with the nuclei of Nitrogen atoms. In all this 300,000 there were only 8 deflected paths.

One of the most interesting things in these photographs is that the point of collision is shown by the commencement of the deflection, and that at this point there are two branches or two tracks. One is the track of the proton dislodged from the nucleus of the Nitrogen atom, and the other is the track of the disintegrated Nitrogen atom. There is no sign of a third track to show where the Alpha particle or bullet has gone after the collision, and from this fact it is concluded that the bullet becomes lodged in the target, or, in other words, that the flying proton links up with the Nitrogen nucleus.

In connection with the ionisation of gases, Professor Lindemann (Oxford), with other two experimenters, has succeeded in making an individual atom produce sound in a loud speaker, though we are not quite the length of making an atom speak. In the experiment referred to, a powerful electric field is maintained between two

electrodes, and the ions formed by the bombardment of a single Alpha particle produce sufficient new ions (charged atoms) to give a momentary electric current, which may be amplified by valves, so that it can operate a loud speaker.

CHAPTER IX

THE CONSTRUCTION OF A CRYSTAL

It is well known that the beauty of a crystal is due to its symmetrical construction. Some of us have boyhood recollections of growing crystals of large size. We suspended a small crystal of alum in a heated solution of alum, and then letting it cool very slowly, the crystal gradually grew larger until we had a very large crystal which showed the identical crystalline form of the smaller one.

We know that the process of crystallisation enables the chemist to get rid of impurities, and that this is used in practice by the sugar refiner, the salt manufacturer, and others, to produce pure materials. The manufacture of artificial rubies and other gems is due to crystallisation, and sheets of mica are obtained from large crystals. We are all familiar with the use of the crystal in wireless telephony.

Crystals have been things of interest since early times, and the most beautiful is the diamond, which is beyond our powers of production. Attempts have been made to form diamonds under great pressure in a highly heated crucible, but all the success has been a few miniature diamonds of microscopic size.

The idea was suggested by the discovery of very small diamonds in a meteorite reaching this Earth from space. Could the chemist not imitate Nature? It was evident that Nature had used some great pressure in crystallising the diamonds in the meteorite.

This pressure had been brought about by the sudden cooling of the exterior, and it was evident that the heat of the interior had been intense. Could the heat not be imitated by an electric furnace and the necessary pressure by sudden cooling? This was tried in the following manner:

It was necessary to provide the material, but there was no difficulty in this, as the diamond is composed entirely of carbon. The chemist placed a modest quantity of this in a crucible, in which was some iron, to imitate the meteorite. The crucible was raised to a very high temperature (5000° Fahr.), and then it was suddenly cooled, in order to produce great pressure. It could not be cooled by dipping it in water, for the intense heat would form a gas on the outside of the crucible, and this jacket would act as a heat-insulator and prevent the sudden escape of heat that is desired. This difficulty was overcome by dipping the crucible into molten lead. It might seem ridiculous, cooling a substance with hot molten metal, which itself is at a comparatively high temperature, but the cooling effect is apparent when we compare the temperature of the iron (5000° Fahr.) with that of molten lead,

which is 606° Fahr.; a cooling of more than 4000° Fahr.

The carbon was found to have crystallised, the diamonds being secured by dissolving the iron with acids, but the size was very disappointing; as already stated, the diamonds were microscopic.

In addition to well-known crystals such as precious stones, salt, sugar, ice, borax, quartz, etc., we have the metals, all of which are of crystalline formation.

For more than a century, chemists have looked to crystals as possibly giving a clue to the arrangement of molecules and atoms in the construction of matter, and only now are we meeting with success with the aid of X-rays.

It will be well to refresh our memories regarding the different conditions in which we find matter. We picture *solid* matter as a condition in which the attractive forces between the molecules lock them in their places, but leave them free to vibrate, and thus produce the temperature of the substance. We know that the particles of all matter are in vibration, and that the temperature is due to the rate of vibration. In a solid we may picture the attractive force as having got the upper hand of the natural motion of the molecules. In the crystal the molecules are arranged in symmetrical form.

We picture a *liquid* as being a condition in which the molecules are free to roll over one another. The attraction between them is sufficient to enable them to keep together in a

mass, but insufficient to enable them to give a definite form to the substance. The cohesive power is greater in the case of solids than liquids.

In a *gas* we see motion the complete master. The molecules in a gas are in violent motion, like a swarm of bees, darting about in all directions. It is this motion which causes them to exert pressure on the containing walls. It is this pressure of motion which distends the covering of a balloon, so that when we crowd the moving molecules together they may burst the walls of the balloon. A Gas has neither size nor shape; a Liquid has size and no shape; a Solid has both size and shape. The distance over which a gaseous molecule moves is small indeed. It does not move far before it collides with another molecule, but it is travelling with a speed of 1800 metres per second, which is equal to 60 miles per minute. That is the speed of a Hydrogen molecule at a temperature of Zero (Centigrade). The molecules of Oxygen and Nitrogen in the atmosphere are moving at a much slower rate; somewhere about 15 miles per minute. It is the motion of these molecules which determines whether the matter is solid, liquid or gaseous. Therefore, by heating or chilling matter, we may alter its condition. We boil water and convert it into a gas, or we chill a natural gas—say the air—to a very low temperature, and turn it into a liquid, and at a still lower temperature it becomes solid ice (composed of air).

The Construction of a Crystal

There are solids and solids : every solid is not a crystal. For a very long time it has been observed that the crystal is quite peculiar. Before the introduction of X-ray analysis, it had been observed that there are six systems of crystals, and also that there are no less than thirty-two different classes of crystals ; a great deal of knowledge had been obtained concerning crystals. Even the Ancients knew that quartz was a six-sided crystal. Now we know hundreds of thousands of different crystals.

It is long since it was discovered that most crystals had peculiar action on a beam of light. In passing through the crystal the light splits up into two components vibrating at right angles, instead of their being in many planes. It must be remembered that there is no surface to the ether, so that we cannot have waves all in one plane, as on water. The ether waves, being within the ocean of ether, may lie in any plane. In the case of a tourmaline crystal one of its two components is absorbed, and plane polarised light is thus obtained; we have polarised the light. This property of the crystal came to be used as a means of testing crystals ; it became an optical probe, by which the kind of crystal might be identified. This method quite revolutionised the study of rocks.

In passing, it may be observed the structures of crystals were used in the study of reflected and diffracted beams of light, and more knowledge was obtained regarding the nature of

light. By the use of the much shorter X-rays our knowledge has been extended much further.

The X-ray waves have revealed the intricacies of the crystal structure, which produces no apparent effect upon waves of ordinary light. The converse of this is also true in that the crystal has shown us the nature of X-rays. The nature of X-rays was a puzzle at first; we thought they were not like light; we could not reflect them nor refract them, but the crystal has shown by diffraction that they are waves.

The optical methods of analysing a crystal merely told us the optical classification of the crystal, whereas the X-ray method tells us the actual distances that separate the molecules which go to form the crystal unit, and even the position of the atoms which form the molecule.

In addition to analysing a crystal by chemical means, a minute crystal may be examined under a microscope, and the nature of the crystal determined. This method is of much importance to the Geologist, the Botanist, and the Pathologist.

In the middle of the seventeenth century it was known that the quartz crystal was always six-sided, the faces of which lay at an angle of 60 degrees to one another; and that the top was in the form of a pyramid. It was observed that crystalline form was a specific property of the substance.

The crystals of common salt are always in the form of a cube. The size of the faces may vary,

but the angle of inclination is always the same. Here is a drawing (Fig. 33) of the construction of a crystal. This drawing was made in the eighteenth century, but it gives the basis of crystal construction.

A salt crystal may be easily cleaved into flakes parallel to any cube face, but not in any other direction; a large crystal may be reduced to any number of cubes by the aid of a very fine blade. We can imagine a point when the blade is too coarse to cut further cubes, and we can picture a much further point when we reach in imagination the last cube, which is composed of eight atoms, forming the crystal unit. It is the arrangement of those units which gives the crystalline substance its symmetrical form.

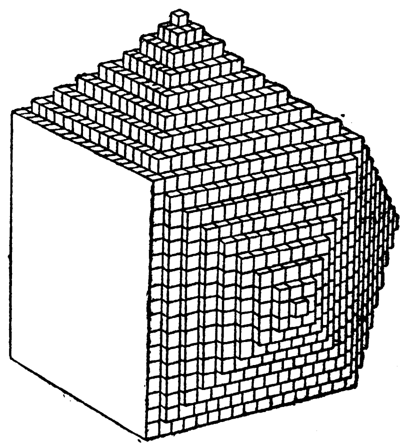


FIG. 33.—A CRYSTAL STRUCTURE.

In the formation of crystals we picture the molecules arranging themselves (by attraction) side by side. As the water gradually evaporates, the molecules get closer together, and there is a regularity in the building. The regular arrangement of molecules produce the regularity of form of the crystal.

Atoms form the molecule, and also form the crystal unit, while innumerable crystal units form the crystal.

The action of these planes of molecules is analogous to the diffraction grating in connection with ordinary light; it arranges light into its different wave-lengths, and thus produces a spectrum. A diffraction grating is composed of a very large number of very fine lines ruled on a very smooth surface of glass or speculum metal.

The diffraction grating of to-day, which may have as many as 28,000 parallel lines per inch, is analogous to a prism, but acts in an entirely different manner; it diffracts the light instead of refracting it. The prism bends the ether waves; the lines of the grating diffract the ether waves, in somewhat the same manner as a paling reflects sound-waves and produces an echo.

It might be asked why we do not rule a grating to deal with X-rays, seeing they are of the same nature as visible light. The answer to such a question is that it is impossible from the mechanical aspect. Why? Because the ether waves known as X-rays are ten thousand times closer together than the ether waves of visible light. The highest frequency of X-rays is that produced by the radium atom. It so happens that the space from crest to crest of a series of X-ray waves is of the same order as the spacing between the molecules of ordinary solid matter.

The idea of using a crystal as a grating for X-rays was suggested by Dr. Laue in 1912. He

was at one time an assistant to Planck, the creator of the quantum theory (which we will consider later), but it was Sir William Bragg who invented the X-ray spectrometer, the arrangement of which is shown in Fig. 34.

The X-ray tube (*X*) is enclosed in a lead-lined box.

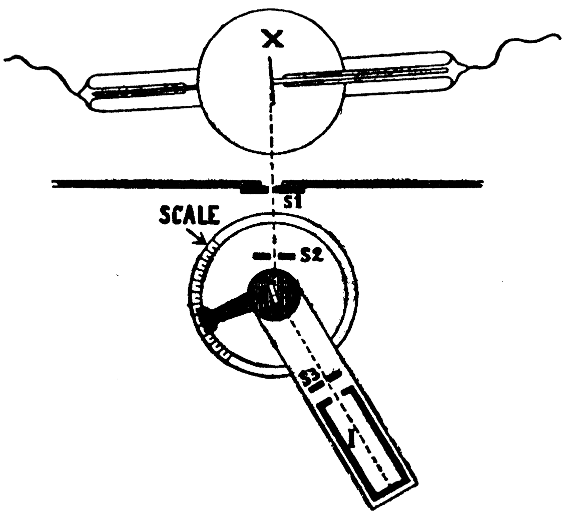


FIG. 34.—X-RAY SPECTROMETER.

It will be seen that a beam or pencil of X-rays is produced by passing the rays through slots in lead screens, *S*1 and *S*2. This pencil of rays falls on the crystal *C*, but they will only be detected when they fall at a certain angle to the crystal face. The crystal is therefore mounted on a revolving table so that the crystal may be turned into the correct position. When this is found, a flash of rays is reflected from the crystal, but it

is, of course, invisible, as X-rays do not affect our vision. A beam of the reflected rays passes through slot ($S3$) and enters a small ionisation chamber (I), which is mounted so that it can rotate about the same vertical axis as the crystal table. This chamber is filled with sulphur dioxide, which is a gas that absorbs X-rays, having become

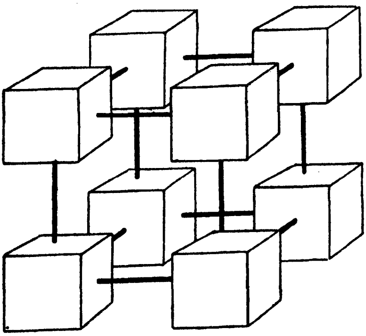


FIG. 35.—CONSTRUCTION OF A CRYSTAL UNIT.

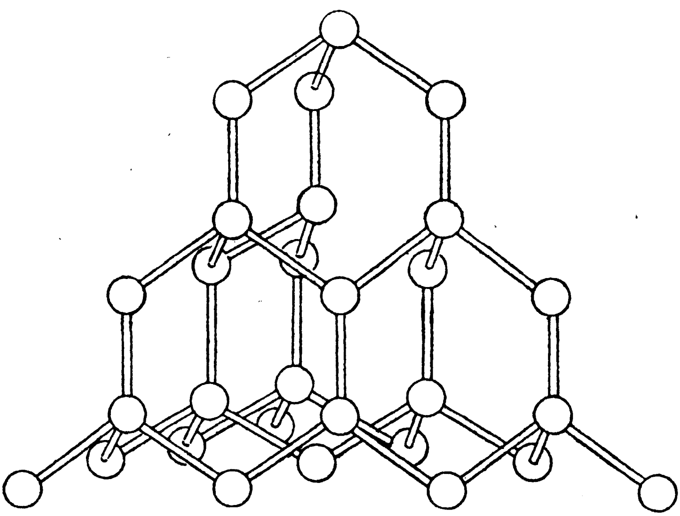


FIG. 36.—MODEL OF A DIAMOND CRYSTAL.
The atoms are arranged in layers, one of which is shown in Fig. 37.

ionised, and builds up a charge upon an insulated electrode within the ionising chamber. This elec-

trode is connected by a fine wire to an electroscope which will measure the rate of charge. The electrode is connected to a wire which enables it to be earthed—and thus discharged at will.

One of the first achievements of the apparatus

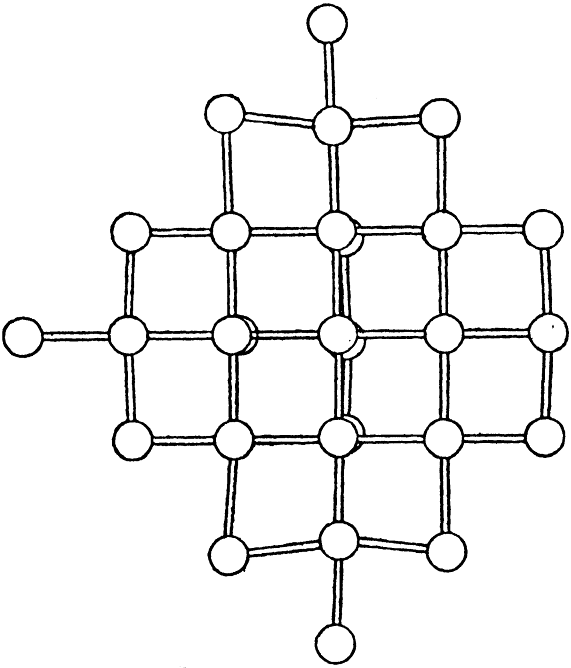


FIG. 37.—A STRATA OF DIAMOND CRYSTAL.
The layers are built up as in Fig. 36.

was the determination of the special arrangement of the atoms within a crystal.

The crystal unit is like a piece of lattice-work, and the atoms are arranged as in Fig. 35.

The arrangement of the carbon atoms forming a crystal unit of the diamond is seen in Fig. 36.

The different layers will be observed, and one of these is shown in Fig. 37.

There is no slipperiness between the layers in the diamond, which lie closer together than in graphite. The hardness of the diamond is due to the fact that the layers have a strong hold upon each other. We may picture the slip taking place as in Fig. 38, from *A* to *B*, and then to *C*.

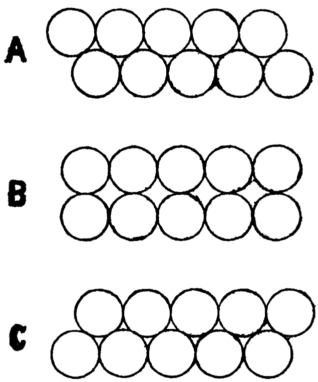


FIG. 38.
CAUSE OF SLIPPERINESS.

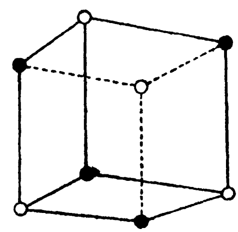


FIG. 39.—CRYSTAL OF ROCK SALT.
The open circles represent Chlorine atoms, and the black dots represent Sodium atoms.

The arrangement of the atoms in the crystal of a compound is shown in the diagram of a crystal unit of rock salt, Fig. 39.

The chemical symbol of Salt being NaCl tells us that the molecule is composed of one atom of Sodium and one atom Chlorine. In the diagram, the open circle represents the chlorine atom, and the black sphere represents the sodium atom. It will be observed that atoms are placed alternately to each other in the corners of the cube.

The next achievement, a much more difficult one, was to determine the position of the atoms within the molecule, but this has been done to some extent by the relative measurement of the intensities of diffraction as revealed by the X-rays, along with all the existing knowledge of the chemical and physical characteristics of the atoms and molecules.

About this time, Moseley carried out a series of elaborate experiments in which the X-rays were produced by targets made of various elements. These targets or anticathodes were mounted on a travelling carriage situated within the X-ray tube. Each element sent out its own wireless message of ether waves (X-rays) when bombarded by the discharge of electrons. There could be no mechanical control of the travelling carriage as it was within the vacuum tube, so a piece of iron was affixed to the carriage, and this could be attracted by a magnet from without the tube.

In Fig. 40 we have a representation of a number of X-ray spectra.

It will be observed that the lines in the diagram rise in frequency. The two lines advance in frequency with each atomic number, as it were in steps, and this is a very significant fact. It will be understood that the atomic number of an element is its position in the Periodic Table. If we place the atomic numbers opposite the spectrum of the element, we find that the higher atomic number the higher frequency. This seems

to mean that the nucleus of each element differs from that of its neighbour by one unit charge of positive electricity.

Originally there were six missing steps, so we might infer that there were six elements undiscovered, but all empty places have been filled now.

It may be remembered in passing that the X-ray study of crystals gives us mental pictures of the property of metals, which we call *ductility*.

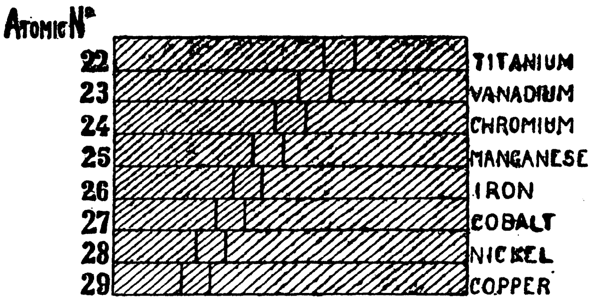


FIG. 40.—X-RAY SPECTRA.

Metals can be drawn into wires. We know how Osmium and other rare metals can be drawn into these very fine wires which are used in electric glow-lamps, and which become incandescent with one-half of the current required to incandesce the older carbon thread.

Gold can be hammered into leaves, so that the gold contained in a sovereign may be spread out to many acres. It is owing to the ductility of gold that we can stamp out beautiful ornaments, etc.

This phenomenon of ductility may be explained

by the fact that the atoms are in layers, which can slip over one another without letting go their hold.

The *hardening* of a metal means the prevention of this slip. Iron is converted into steel by the addition of a very small percentage of carbon. We might picture the carbon atoms filling up the spaces between the iron atoms, and thus preventing the slip by applying a sort of strain among the molecules. The *annealing* of a piece of iron is the releasing of this strain.

This slipperiness of the layers in a crystal is very apparent in graphite, which is used as a lubricant. The same slipperiness accounts for a person slipping on a black-leaded surface.

It is difficult to realise that the whole difference between lampblack, graphite, and the diamond is the difference in the arrangement of the same carbon atoms. That there is a marked difference in the placing of the atoms is apparent from the difference in density, graphite being 2·30, and the diamond 3·52. Even the diamond may be said to be full of holes. The models which are made to represent the crystal units seem puzzling at first, as we are not so accustomed to deciphering three dimensions as the two dimensions on a flat paper drawing.

It is possible that the molecules in a solid may be so lightly held together that those on the outer layer may escape. An example of this is naphthalin, a solid having evaporation. Naphthalin is one of the products of coal-tar, and is used very largely in the manufacture of many dye-stuffs, such as

black, indigo, scarlet, red, certain greens, yellows, brown, violet and sky-blue.

The fact that the freezing-point of water is lowered by compression was predicted many years ago by Lord Kelvin's brother, the late Professor James Thomson.

If a wire is placed around a block of ice, and the wire is pulled downwards by two heavy weights as in Fig. 41, we have a demonstration of this. The wire sinks through the ice, the ice being

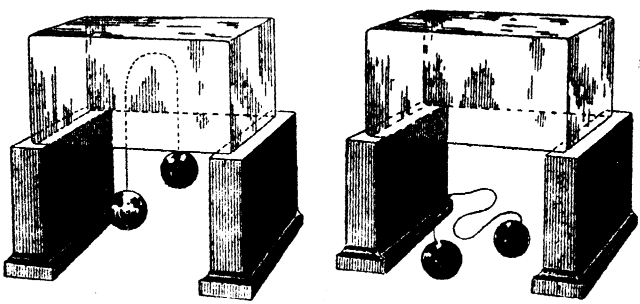


FIG. 41.—CUTTING BLOCK OF ICE.

melted under compression, but the ice joins up again, so that by the time the weights have fallen on to the floor the ice is still a complete block. The pressure of the wire breaks down the structure of the ice, and some molecules are set free, but these link up with other molecules. What really happens is that some of the solid ice becomes liquid water, which is squeezed out from under the wire and slips round the wire to the vacant space above it, where it joins up with the ice on the two sides of the cut.

CHAPTER X

MIXED ELEMENTS

We have seen that in the laboratory it is possible to deal with individual atoms, and to photograph the traces of flying atoms as they pass through a cloud, formed in a vessel. There has been a remarkable advance in our knowledge of atoms, and this has been made possible by the discovery of radioactive substances. One interesting addition to our knowledge has been the explanation of how it is that the atomic weights of some elements have fractions added to the whole numbers. If the atoms are made up of definite units (protons and electrons), and if these cannot be divided, how can there be fractions? The explanation is simple; it is found that some elements are a mixture of different atomic weights, and that ordinary methods only deal with the average of these. An element may be composed of a mixture of atoms of, say, 20 and 22 atomic weights. This is the case in the element Neon, which is one of the inert gases. Suppose the atom to be composed as under:

90% of the atoms with atomic weight	20 =	1800
10% " " " " "	22 =	220
		2020

Then take the average, 2020, divided by 100, equal 20·2, which is the atomic weight of Neon (see list, page 36). In Fig. 42 we have a diagrammatical representation of two Lithium atoms, one of which contains only 6 protons and 6 electrons, while the other contains 7 of each.

In the case of Neon, one of the isotopes of the mixed elements has 20 positive particles,

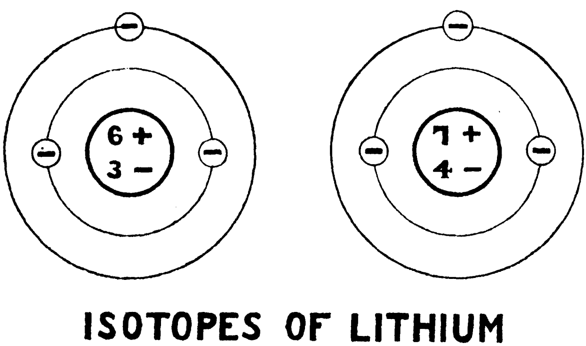


FIG. 42.—LITHIUM ISOTOPES.

One atom contains 6 protons and 6 electrons, while the other contains 7 of each. It will be observed that the rings each contain 3 outside electrons, so that the chemical properties are the same.

with 10 electrons in the nucleus and 10 outside. The other isotope has 22 protons and 12 electrons in the nucleus, leaving 10 still inside to make the balance of positive and negative, $22 = 12 + 10$, whereas in the other case, $20 = 10 + 10$. The case of Chlorine is more complicated ; the fractions in the atomic weight of Chlorine (39·40) may be explained as a mixture of 35, 36, 37 and 38 in different proportions. The work is not all hypothetical ; these figures are obtained from Chlorine

by actual experiment, and explain the fractions in the atomic weight.

If you look at the list of elements again (page 36) you will see that many of these must be mixtures; some of them are very complex. By experiment we find that Potassium (39·10) is a mixture of six different atomic weights, while Tin (118·7) has at least seven varieties, and the inert element Xenon (130·2) has probably no less than nine varieties.

The word *Isotopes,* which is used to describe these mixed elements, was suggested by Professor Soddy, and is derived from the Greek words—*Isos* and *Topos,* meaning the same place, and indicating that those atoms, though differing in atomic weight, occupy the same place in the Periodic Table.

With the advance of knowledge, the fractions in atomic numbers have become very real things, having been obtained by different experiments, and all agree to a wonderful degree of accuracy; it is no mere jumble of numbers and fractions.

It should be realised that, chemically, there is no difference in the mixed atoms which go to form an element, their spectra are identical. The atoms are the same physically and chemically, and differ only in their atomic weight. This is quite explainable with the aid of the nuclear theory of the atom. The nuclei of atoms might vary in their mass, but yet, at the same time, possess properties in common with each other.

Dr. F. W. Aston, of Cambridge, who has done

most of the work in connection with isotopes, has given us a mental picture of the size of the atom. He starts with a cube of lead, weighing 11·3 kilogrammes, and measuring 10 centimetres. He cuts this into eight cubes by dividing it through its centre in the manner shown in Fig. 43.

(No. 6 cube is hidden beneath No. 5 and behind No. 2.) He goes on dividing each diminishing size of cube, using the above method of cutting at each operation. After the first operation he will have cubes measuring 5 centimetres (about 2 inches). Each size will be one-half the length, and one-eighth of the weight of the preceding cube. Confining attention to the weights, he points out that the weight after the second operation of cutting will be 178 grammes, and at the fourth operation it will have diminished to 2·78 grammes. It will go on disappearing very rapidly at each cut, and at the ninth operation the resulting cube will be just weighable in an ordinary chemical balance. The last operation possible, without breaking up the lead atom, will occur at the twenty-eighth cutting operation. The twenty-sixth cube contains sixty-four atoms, the size, distance apart, and general arrangement of which can be represented with

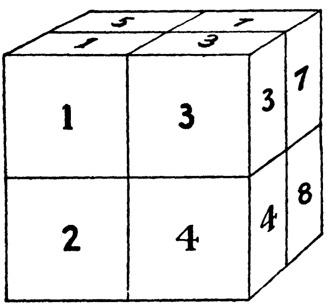


Fig. 43.—Cutting a Cube.

considerable accuracy by means of X-ray work already referred to.

Aston then gives us a table showing at what stages the different methods of analysis break down, and he points out the great superiority of the microscope.

The measures and weights of these cubes require such an array of ciphers in figures that they do not mean much to the layman, so I have simplified the tables by omitting these, and merely made a list as follows :

The ordinary chemical balance can go no further than the ninth cube.
The spectroscope can go no further than the fifteenth cube.
The ordinary microscope can go no further than the eighteenth cube.
The ultra microscope can go still further.

In Radioactivity we can detect the individual atom twenty-eighth cube. Aston points out that if these individual atoms contained in cube No. 1 were spaced out 1 millimetre apart, they might span the whole universe. Is it not remarkable that we can photograph the track made by a single atom (Alpha particle) ? Of course, it is the high velocity of the atom which enables us to detect its presence ; its mass is infinitesimal, but its energy is great, and can cause a splash of light on the phosphorescent screen.

The atoms of an element are all identical, so

far as ordinary chemical methods are concerned, because the chemist can only deal with myriads of atoms at a time, and they have all the same chemical property for the same element; it is the physicist who deals with the individual atoms.

In the case of elements which are not radio-active, the presence of isotopes can only be detected by the direct measurement of the masses of individual atoms, and we have seen how this

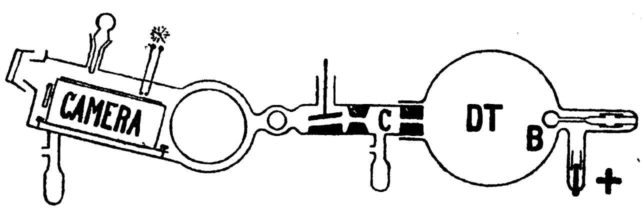


FIG. 44.—PHOTOGRAPHING POSITIVE RAY SPECTRUM.
This apparatus gives a degree of accuracy of measurement of the positive particle which is not possible by earlier positive ray analysis.

can be done with the aid of the positive ray method of analysis.

A degree of accuracy is necessary, of which the earlier positive ray analysis was not capable, but the required accuracy was attained by the formation of a spectrum. The spectrum was got in the following manner. A diagram of the apparatus is shown in Fig. 44.

One of the reasons for the lack of precision in the earlier positive ray method is due to the fact that many rays are lost by collision in the narrow channel ray tube through which the charged

atoms pass. The difficulty was overcome by replacing the brass or copper tube by fine apertures made in aluminium; the improvement being due to the fact that aluminium appears to suffer very little disintegration during the bombardment; and an additional improvement was obtained by exhausting the space between the slits to the highest degree possible by means of a tube of charcoal (placed in liquid air as already described).

The discharge tube (Fig. 44) is seen at *DT*, and is an ordinary X-ray bulb. The Anode or positive electrode is shown at +. It has a shield of aluminium to protect the glass walls of the tube.

The Cathode or negative electrode is made also of aluminium. It is seen in the neck of the bulb at *C*. It will be remembered that it is from this point that the bombarding electrons are flung, and these would heat the opposite end of the bulb to melting-point. To protect this end of the tube there is a silica bulb, *B*.

The electrons are shot off from the negative electrode by means of a large induction coil; about 100 to 150 watts are passed through the primary of this coil, and the pressure is between 20,000 and 50,000 volts.

The arrangement of the negative electrode is shown in Fig. 45. This is an enlargement of part of Fig. 44.

The negative electrode itself is seen at *C*. The neck is fixed by a brass collar *BC* to the

connecting tube *CT*. There is a wax joint which is kept cool by water passing through a surrounding tube. The gas to be analysed is admitted through a side tube which enters at *E*.

The aluminium slits are shown at *S*1 and *S*2. They are made in the following manner: A small cylinder with a hole or bore measuring 1 mm. is made first. The small cylinder is then crushed with a hammer on an anvil, until the hole becomes a very narrow slit about 0·3 mm. wide. It is then

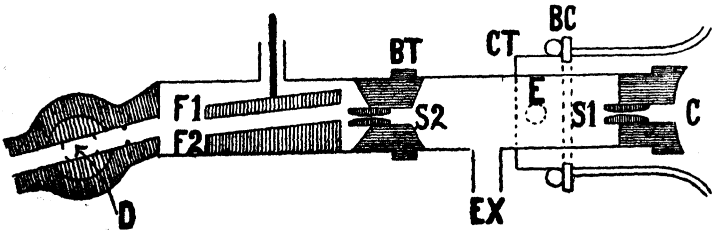


FIG. 45.—CATHODE OF SPECTROGRAPH.
This is part of Fig. 44 enlarged.

pressed between two jaws until the required fineness of slit is obtained (0·02 mm.). There must be a hole pierced through the negative electrode to permit the positive rays to pass through to the observing chamber, and so the centre of the cathode is pierced with a hole measuring 3 mm., and into this hole is fitted one of the aluminium tubes with the fine slit in it. A brass tube, *BT*, with a brass plug, holds the other aluminium tube with slit No. 2. These slits are adjusted to a parallel position by means of the different patterns they make when light is

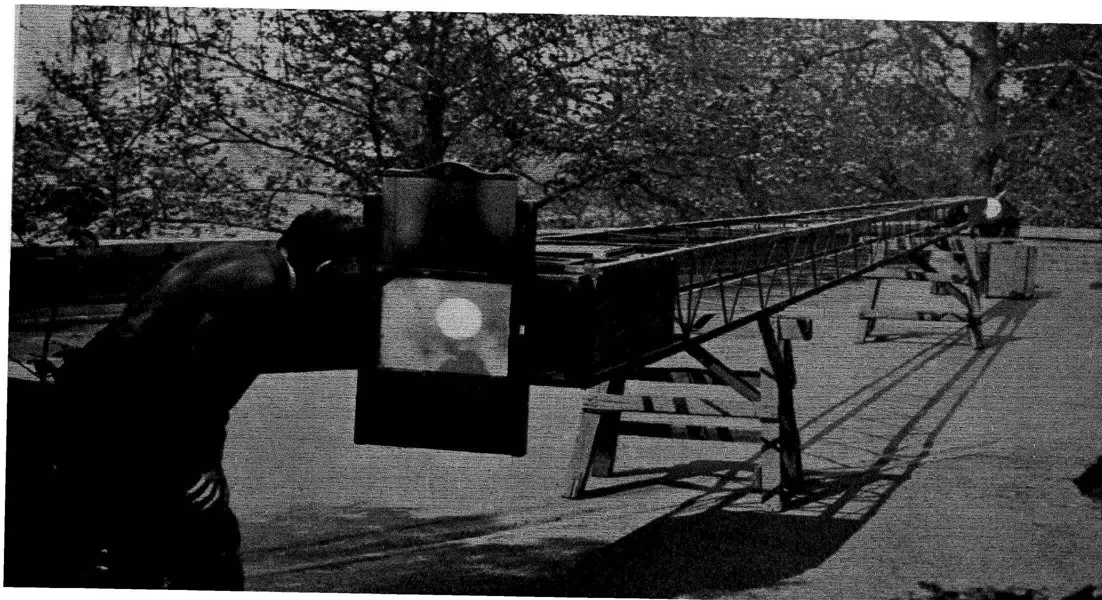


Photo *Pacific and Atlantic Photos Ltd.*

SOLAR ECLIPSE CAMERA

This camera, which measures 45 feet in length, was used by the Astronomer Royal during the Solar Eclipse of 1927. The photograph shows the camera being tested beforehand. A concave mirror, seen at the far end, reflects the light into the camera and produces an image of the sun on the screen or photographic plate.

passed through them. At *EX* is shown the position of the exhaust tube through which the gas is exhausted to produce the high degree of vacuum necessary.

It will be remembered that the atoms passing through these slots are travelling with different velocities, and the purpose of the apparatus is to spread these out into a spectrum as is done to the mixture of ether waves of light by means of a glass prism. The spreading out in the case under consideration takes place between two parallel flat brass surfaces, $F1$, $F2$. The upper surface, $F1$, can be charged to give a pressure of several hundred volts, thus producing an electric field between $F1$ and $F2$. The source of electricity is a battery of small storage cells. The reason for the sloping of the plate is to suit the angle of the mean ray of the part of the spectrum which is to be selected by two diaphragms, the positions of which are indicated by the arrow *D*.

The rays, after passing through these diaphragms, pass between the pole pieces of a large electro-magnet, the faces of which are circular, and the space between the poles measures 8 mm. Current for the electro-magnet is taken from a special set of large accumulators. The discharge is protected from the strong field of the magnet by soft iron plates (not shown in the diagram).

The camera in which the spectrum has to be photographed is made of brass. It is shown in Fig. 44, at page 166.

A small phosphorescent screen is used for

testing purposes; it is placed within the camera.

In arranging the experiment, the electric field is applied, and the magnetic field is brought into operation, being just sufficient to bring the light spot of the spectrum on to the phosphorescent screen. The exposure may range from twenty seconds for some lines to thirty minutes for others; fifteen minutes is usually enough. The masses of the particles are deduced from the positions of the spectrum lines, and it is from their relative positions that the deductions are made. Any known element could be taken as a standard, but Oxygen is selected; it gives three suitable reference lines. It will be observed that its atomic weight (16) indicates that it is a simple element and not a mixed one, as in the case of those elements whose atomic numbers contain a fraction.

If carbon-dioxide is examined, it will give the oxygen lines and the carbon lines on the same photograph.

It is a very significant fact that we have not been able to discover a particle of mass less than a hydrogen atom, and, as already pointed out, this leads to the conclusion that the unit of positive electricity is in fact the nucleus of the hydrogen atom, which is composed of one electron and one positive particle or proton. In other words, the positive unit is a hydrogen atom robbed of its satellite electron. The mass of the proton has been measured, and is found to correspond

exactly with the mass of a neutral hydrogen atom.

While it is apparent from a list of the atomic weights of the elements that there are more mixed elements than whole number ones, or simple elements, it is interesting to note that the simple elements are present in greater proportion in nature, as, for instance, in the crust of the Earth.

The following are a few notes of things it is helpful to keep in mind when dealing with isotopes:

1. The nuclear charge of an atom is determined by the difference between the numbers of positive protons and negative electrons contained in the nucleus.

2. The atomic weight depends only on the number of the protons, the mass of the electrons being insignificant in comparison with the protons.

3. The proton, though so much more massive than the electron, is very much smaller, the mass being concentrated.

4. Two atoms with the same nuclear charge can readily have different masses, and therefore different atomic weights; they are isotopes occupying the same position in the Periodic Table.

5. Isotopes cannot be separated by chemical methods.

CHAPTER XI

EXPERIMENTS WITH THE ETHER

In his address to the British Association at Oxford in 1894, Lord Salisbury, speaking of the ether said :

" It may be described as a half-discovered entity. For more than two generations, the main, if not the only, function of the word 'ether' has been to furnish a nominative case to the verb 'to undulate.' Lately, our conceptions of this entity has received a notable extension. One of the most brilliant of the services, which Professor Maxwell has rendered to Science, has been the discovery that the figure which expressed the velocity of light also expressed the multiplier required to change the measure of the static electricity into that of dynamic or actual electricity. The interpretation reasonably affixed to this discovery is that as light and the electric impulse move approximately at the same rate through space, it is probable that the undulations which convey them are undulations of the same medium. . . . But the mystery of the ether . . . remains even more inscrutable than before. Of this all pervading entity we know absolutely nothing except this one fact, that it can be made to undulate."

It is with the waves in the ether that the following experiments have been made; some are of historical interest, others are recent experiments, most of which have proved negative in result, but are interesting from an experimental point of view.

We know that the ether waves of light travel with a velocity of 186,000 miles per second. This was discovered as early as 1675, and the discovery was made by observation of Jupiter's satellites. Jupiter is rich in moons, having no less than nine. The observation may be understood by the following statement, though it is not quite the way the observation was made. At some times of the year a satellite seemed to be later in appearing from behind the giant planet than at another time. There could be no alteration in the speed of the satellite, and the only reasonable explanation was that light takes time to travel through space.

Perhaps the simplest way of looking at the subject is this. During the Earth's journey around the Sun, it alters its distance from Jupiter. The greatest difference is the diameter of its orbit, which is roughly 186,000,000 miles; the Earth being about 93,000,000 miles from the Sun. The appearance of one of Jupiter's satellites was about a quarter of an hour late. Therefore it will take light a quarter of an hour to travel 186,000,000 miles. There are almost a thousand seconds in a quarter of an hour, so that light travels at 186,000 miles per second (186,000,000 divided by 1000). What interests us at present is that the velocity

of light has been timed in its passage from place to place on the surface of the Earth.

Before the astronomical discovery of the velocity of light, Galileo tried to time it in its passage from one mountain to another, and the idea was quite a good one, though he failed in his attempt. The fault lay in the method. Galileo and a friend took up their positions on two mountain-tops. Galileo was to open his lantern, and the friend, as soon as he saw the light, was to open his, and thus signal the arrival of the light. In this way Galileo hoped to be able to time the transmission of light over the double journey. Of course, the attempt met with failure, for the time required to open and close the lanterns was much greater than the whole time occupied by light in making the double journey. The same idea was tried by a French physicist (Fizeau) nearly two hundred years later (1849). He timed light over a course of 5½ miles. The thing seems impossible! Instead of covering and uncovering lanterns he opened and closed an aperture at the source of light many times in each second of time. His method was very ingenious. He revolved a toothed wheel so that each tooth closed and opened then closed the aperture as it passed in front of it. When a space between the teeth came opposite the aperture, the ether waves of light passed out to the distant station. Here it was reflected back again by a mirror, and they could enter the same aperture.

If light could travel instantaneously; if it

took no time to go and return from the distant station, then it could enter by the same tooth space through which it left, but if it arrived back when the tooth had blocked the aperture, then it took time, and the time could be calculated.

There is a beam of light which passes through lenses and is focused into a pencil and then reflected from a glass plate so that it passes along a telescope. On reaching the distant station it is again focused by a lens and strikes a concave mirror from which it is reflected back to the telescope. The tooth-wheel is arranged to open and shut the aperture. On its return journey, the light enters the telescope and passes through the glass plate already referred to, and is observed through the eyepiece of the telescope.

When the wheel is rotated slowly, the light will have time to make the double journey and re-enter the telescope through the same aperture. During the time necessary for this, the wheel will not have made any appreciable movement. Looking through the eyepiece, the light will be seen to flicker, as the teeth pass in succession, but if the teeth open and close the aperture more than eight or ten times per second, the persistence of vision comes into play (as in the cinematograph), and the flickers disappear ; a steady light appears to persist. Before the flicker disappears we will reach a state of revolution at which the teeth will intercept the light on its return ; the image will disappear. If the speed of the wheel is known, we can tell the time required for it to move

forward one tooth, and during this time the light has travelled to and from the distant station, therefore the velocity of the light can be calculated. Fizeau found this to be 315,000,000 metres per second, which is equivalent to 186,000 miles per second.

The speed of the wheel may be timed to let the light pass through one space, and re-enter through the succeeding space, and an increase in this speed will enable the succeeding teeth to block the way of the returning light.

This experiment is historic; it was the first instance in which light was proved to occupy a finite time in traversing terrestrial distances. It was followed in 1850 by an experiment known as Foucault's method, the one already described being known as Fizeau's method. He employed a rotating mirror, the principle of which was already known, having been previously employed by Wheatstone to determine the duration of the electric spark. As early as 1838, Arago had proposed the use of a rotating mirror to determine the velocity of light. He also pointed out that with its aid the velocity of light in both air and water might be determined.

Professor Michelson (U.S.A.) invented an improved method. The most important alteration was the placing of a lens in a position between the revolving mirror and the reflecting mirror instead of having it between the aperture and the revolving mirror, as is shown in the diagram of Foucault's arrangement. In this way

the brightness of the image is maintained. By this means, Michelson obtained more accurate results.

In conjunction with Morley, Michelson sought to find out if there was any effect shown by the passage of the Earth through the ocean of ether. Work had already been done on this subject by Mascart and Farmin. In order to understand the experiment it is well to become familiar with the interference bands produced by light. These are alternate bands of light and darkness, the dark lines being produced by one set of ether waves interfering with another.

We find a suitable analogy of this in the realm of Sound. One steel bar when vibrated will have a frequency of 504 vibrations per second, and if we make a similar bar a shade longer or heavier we can produce 500 vibrations per second. By using the Goold method of vibrating the bars the sounds are very loud.

In Goold's method of vibration a special vibrator is used. This consists of a substantial metal handle in which is fitted an adjustable piece of cane to the end of which may be attached a leather tip of a billiard cue, though the bare cane will also do. The free length of cane is arranged so that it vibrates at the required rate. The steel bars are set vibrating by gently stroking the bar with the free end of the cane, whereupon the bar's vibrations fall into step with the vibrations of the cane. It is a case of the superimposing of small motions.

When the 500 and 504 bars are vibrated separately, the sounds are very similar, but when vibrated simultaneously, the one set of waves interferes with the other, and a crest of one wave coming on the trough of another wave produces a calm or silence, the succession of which we hear in the form of beats. This demonstration of air waves helps us to understand the interference of ether waves.

The interference bands of light may be produced by simple means. All that is required is to split a beam of light into halves, and send them round by different paths, and make them meet again, when there is no guarantee that the waves will coincide crest for crest; the result will be the production of interference bands.

It should be noted that the dark lines do not indicate the obliteration of the ether energy, but merely a redistribution of it; the light ones are correspondingly brighter, and the total illumination is not changed.

Sir Oliver Lodge has devised a plan of showing these interference bands on a lantern screen. He gave a demonstration of this at the Royal Institution in 1892, and the plan was as shown in Fig. 46.

*M*1 is a semi-transparent mirror of thinly silvered glass, causing the beam of light from an electric lantern to break into halves; the first of these half-beams coming in the direction along the arrow from the tail, goes to a mirror at *M*2 and thence to *M*3, and back through *M*1 to the

arrow head. The other half goes in the opposite direction to *M*3, thence to *M*2, and back to *M*1, where it glances off, and is reflected along the line to the arrow head. The two half-beams are therefore re-united along the line from *M*1 to the arrow head. On reaching the lantern screen, the result is interference bands of light and darkness. This is, of course, due to the one set of waves interfering with the other set.

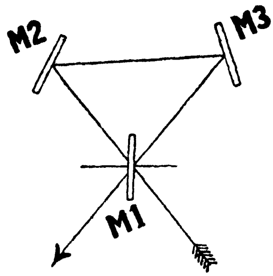


FIG. 46.—DEMONSTRATION OF INTERFERENCE OF LIGHT.

The light is sent round from mirror to mirror, and produces interference of the ether waves composing the light.

One would think that any disturbance of the mirrors would immediately disturb the interference bands, but the table on which the mirrors rest may be struck a heavy blow without causing any such disturbance. Even when a piece of glass is interposed in the path of the waves, there is no shift of the bands. The only way, with this apparatus, of causing such a shift is to accelerate the waves in one-half of the beam, and retard the other half by a moving transparent substance in the line of the waves. For instance, the waves may be made to pass through a stream of water which is kept in rapid motion, and, as has been shown by experiment, if the ether waves of light are sent along a stream of water, they will go quicker

with the current than against it. We must remember that while the ether waves are made to pass through the water, they are not being transmitted by the water, but by the ether; it is not like sound waves carried by a wind, for in that case the waves are air waves. Yet we find the ether waves being helped along by the water, with just about half the speed of the water.

Sir Oliver Lodge suggested that this phenomenon might give a means of detecting a motion of the Earth through the ether of space. His argument was that every vessel of stagnant (non-moving) water was travelling round the sun at the rate of 19 miles per second (1000 miles per minute). Therefore, if a beam of light was sent through it in one direction, it should be hastened; its velocity, instead of being 140,000 miles per second (the velocity of light through water), should be 140,009 miles. Whereas, if the beam is sent through the water in the other direction, it should be opposed by the water (moving with the Earth), and the speed would be only 139,091 miles per second—just as much retardation as there would be acceleration by the other direction. If these two beams are brought together, they should show interference bands.

This was tried by more than one experimenter, and the method of Mascart and Farmin already referred to was as shown in Fig. 47.

L is the source of light. *G* is a plate of thick glass, which reflects the light to the glass plate *P*1. Here it is split into two halves; one half-beam

goes by the lower line to the second glass prism *P*2, and is reflected back along the upper line to *P*1. The other half-beam does the same journey, but in the opposite direction. They are both reflected back again by *P*1 to the glass plate *G*, through which they pass to a telescope *T*. A vessel of stagnant water is placed as shown in the diagram (*W*), so that the one half-beam passes through it in one direction, while the other half-

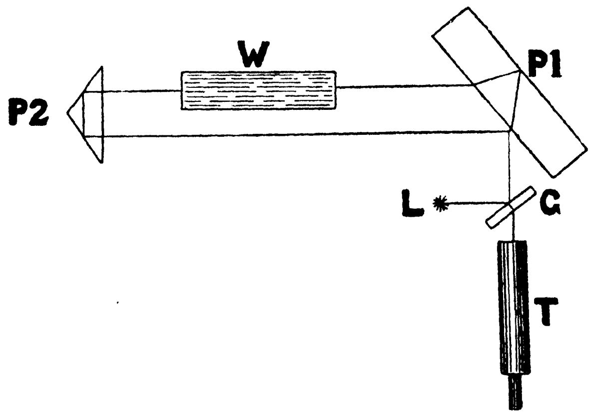


FIG. 47.—LIGHT PASSING THROUGH WATER.

beam travels through it in the opposite direction. The one half-beam ought to be accelerated and the other retarded, and if so they will produce a shift in the interference bands (already existing), when the apparatus is turned in different positions relative to the Earth's motion through the ether, but no such shift is seen; it fails to detect the motion of the Earth through the ether ocean.

Clerk-Maxwell repeated the experiment, as did

Mascart also, using improved apparatus, but all the results were negative.

In 1887, Michelson invented another plan, which has become famous. It consists in looking for interference between the half-beams of light, one of which has been sent to and fro *across* the line of ether drift, and the other has been sent to and fro *along* the line of ether drift.

The beam of light is split by a semi-transparent mirror, set at an angle of 45 degrees, and two ordinary mirrors are set perpendicular to the two half-beams, and are employed to reflect them back to the point they came from, and into a telescope, as in Mascart's arrangement (Fig. 47).

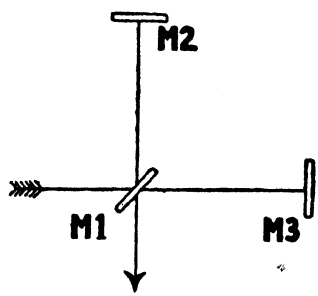


FIG. 48.—MICHELSON'S EXPERIMENT.

Michelson's arrangement is as shown in Fig. 48.

It will be observed that no light passes from *M*2 to *M*1, as was the case in Mascart's method.

In Fig. 48 the light is split at *M*1 (a semi-transparent mirror). One half-beam goes to *M*2 (an ordinary mirror), and is reflected back along its own path, and the other half-beam is treated in the same way by *M*3 (another ordinary mirror). The two half-beams are re-united along the line from *M*1 to the arrow head.

By this method one of the half-beams may be

made to travel North and South, and the other half-beam East and West.

In this arrangement the apparatus has to be very steady, and there must be no change of temperature permitted in the path of either beam. To secure this, the source of light, the mirrors and the observing telescope were all mounted upon a massive stone slab, which was floated in a bath of mercury. It is curious to see heavy objects floating on mercury, but there is no mystery when we consider their relative densities.

The floating slab could be slowly turned round, so that sometimes the one half-beam and sometimes the other would lie along or across the direction of the Earth's motion through the ether. In this way there should be an acceleration and retardation, and a consequent shifting of the interference bands.

The amount of shift would only be as one point in a hundred million, so the difficulty of the experiment is apparent. Indeed, the experiment would fail unless one point in four hundred millions could be clearly detected. Michelson states that his apparatus is capable of detecting a shift of one point in four thousand millions. This is equivalent to detecting an error of one-twentieth part of an inch in a length of 100 miles.

Even with this degree of accuracy, Michelson's method detected no shift. His apparatus behaved exactly as though the ocean of ether had no drift; or, put another way, as if the Earth

carried with it all the ether in its immediate neighbourhood; the result was again negative.

Lodge put the question another way, and asked himself if matter can carry the neighbouring ether with it when it moves. Could he move a lump of matter quick enough to cause it to show a drag in the ether? He made attempts to test this during 1891 to 1897, and his experiments are very interesting.

He took two steel discs, 36 inches in diameter, and clamped them together with a space between them, so that light could pass through. He mounted these discs on a vertical axis, so that he could spin them like a top at a very high speed. He then took a beam of light, which he split into halves, as we have already seen done, by a semi-transparent mirror, allowing one-half of the light to go through and reflecting the other half. This transparent mirror is placed at *M*1 (Fig. 49), and it sends the two half-beams round and round three times (in opposite directions).

In the space between the discs, as shown in the diagram, the light is reflected round by the ordinary mirrors, *M*2, *M*3 and *M*4. The half-beams then re-unite and enter a telescope. If the waves have travelled exactly the same distances, they need not interfere with one another; but usually the distance will differ by a very small fraction of an inch, and this is sufficient to bring about an interference of waves, and consequent interference bands in the telescope. The thing to be observed in the telescope is

whether or not a light band is replaced by a dark band, or *vice versa*. If this happens, it means that one of the half-beams (the one which is travelling in the same direction as the discs) is helped on very slightly, and is equivalent to a shortening of the journey by a quarter of a millionth of an inch in the whole 30 feet, while the other half-beam is retarded by the same amount. If this acceleration and retardation take place,

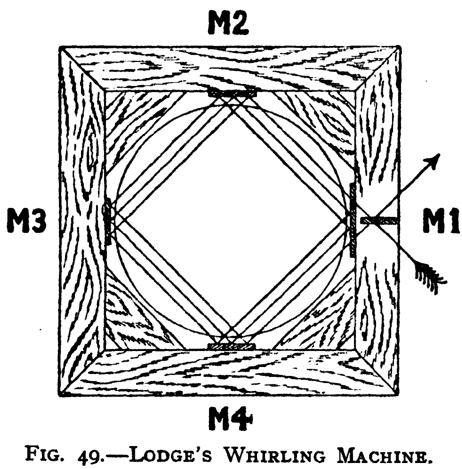


FIG. 49.—LODGE'S WHIRLING MACHINE.

waves which did not interfere on meeting while the discs were at rest will be made to interfere by this acceleration and retardation of the waves; there will be an apparent shift of bands in the telescope.

Sir Oliver Lodge says:

"At first I saw plenty of shift. In the first experiment the bands sailed across the field, as

the discs got up speed, until the cross wire (*of the telescope*) had traversed a band and a half. The conditions were such that had the ether whirled at the full speed of the discs, I should have seen a shift of three bands. It looked very much as if the light was helped along at half the speed of the moving matter, just as it did inside water.

"On stopping the discs, the bands returned to their old position. On starting them again in the opposite direction, the band ought to have shifted the other way too, if the effect was genuine; but they did not; they went the same way as before. The shift was therefore wholly spurious; it was caused by the centrifugal force of the blast of air thrown off from the moving discs. The mirrors and frame had to be protected from this. Many other small changes had to be made . . . until presently there was barely a trace of them (*the shifts*). But the experiment was not an easy one. Not only does the blast exert pressure, but at high speeds the churning of the air makes it quite hot. Moreover, the tremor of the whirling machine, in which from 5 to 9 horse-power is sometimes being expended, is but too liable to communicate itself to the optical part of the apparatus. Of course, elaborate precautions are taken against this."

Lodge describes his experiments in the *Philosophical Transactions of the Royal Society* (1893 and 1897), and there he tells of how he electrified the discs, and also replaced them by a great iron mass, strongly magnetised as an electro-magnet. In neither the electric nor magnetic fields did any shift take place. The effect was always zero

when the spurious results were eliminated. At no practical speeds does the electrification or magnetisation confer upon matter any appreciable grip upon the ether. In no case do the atoms appear to drag any of the ether along, or to meet with resistance in any uniform motion through it.

It is interesting to read Lodge's conclusion, as given in the *Philosophical Transactions of the Royal Society*, vol. clxxxiv. p. 777 :

"I feel confident either that the ether between the discs is quite unaffected by their motions, or, if affected at all, by something less than the thousandth part. At the same time, so far as proof is concerned, I should prefer to assert that *the velocity* of light between two steel plates moving together in their own plane an inch apart is not increased or diminished by so much as the $\frac{1}{200}$th part of their velocity."

That was the conclusion in 1893, but, after that date, Lodge continued his observation and found (1897) he could safely say $\frac{1}{1000}$th part in place of $\frac{1}{200}$th part. He says that the spin was sometimes continued for three hours to see if an effect developed with time.

CHAPTER XII

CONCERNING ETHER WAVES

THE more familiar we become with ether waves the more easily will we understand many of the problems concerning matter, as radiation plays a very important part.

Although we know that there is no surface to the ether in which waves may be formed, and although we have known them to be occurring in all possible planes within the ocean of ether, it is helpful to use water waves by way of analogy. Take again the analogy of a boy standing in the centre of a pond, and armed with a circular float attached to the bottom end of a pole. By means of this he makes waves travel out across the surface of the water. He may demonstrate wave-lengths by first of all moving his float at a low frequency and producing long waves, with a comparatively great distance from crest to crest. Then he may hasten the rate of vibration and send out very short waves, following close upon one another's heels. When considering ether waves, it will be simpler to use the older picture of vibrating electrons producing the waves in place of the Bohr theory.

We know that ether waves are produced by vibrating electrons, so that the float may represent

an electron. In the case of wireless waves, these are produced by electrons surging to and fro in an aerial wire, so that there is direction in the movement. Hence the wireless waves are prolonged; they are all in one plane. In an incandescent body, the electrons are vibrating in all planes, so that we have a mixture of planes among the ether waves. We know how these may be polarised by a crystal.

We may carry the analogy of the pond and boy another step, and picture a cork on the surface of the water imitating the movements of the float which is producing the waves. In the same way we picture an electron set in motion by ether waves, and imitating the motions of the electrons producing the ether waves. In this way we have electrons in the receiving aerial imitating the movements of the electrons in the sending aerial, and producing signals transmitted through space.

Again we have different sending stations, in the aerials of which the electrons move at a different rate for each station, producing corresponding differences in the wave-lengths of the ether waves produced. The stations are known by their wave-lengths. The station calling states its identity, but we could detect a station by measuring its wave-length. In the same way we detect an incandescent element by the wave-lengths of the ether waves which it sends out.

We know that the different elements are recognised by the positions of the lines which they form in passing through a spectroscope. I find

that these lines often seem very mysterious things to the layman, but there is really no mystery.

The light from an incandescent body is a mixture of different wave-lengths, produced by electrons vibrating at different rates. This medley of ether waves produces within us the sensation of vision known as white.

Regarding the medley of ether waves sent out by an incandescent body, we note that so long as every possible wave-length is present, the spectrum will be a continuous one from end to end.

The spectrum is produced by passing a beam of light through a glass prism. The resultant beam has the ether waves spread out into the various wave-lengths contained in the light. The waves are bent out of their normal straight path by the prism. The long waves producing the sensation of red are bent least, and those producing violet are most bent, while between them lie the waves producing the sensation of orange, yellow, green, and greenish-blue. Fig. 50 shows the bending of the rays.

The spectroscope contains a prism or a diffraction grating, which sorts out the various wave-lengths; by passing them through a fine slot they produce a line. The line produced by slower vibrating electrons will appear towards the red end of the spectrum, while those produced by higher frequencies will be towards the violet end. A piece of incandescent sodium is very strong in a certain wave-length, which produces distinct lines in the yellow region of the spectrum.

If we burn a little common salt in a Bunsen flame, and examine the resultant spectrum by means of a spectroscope, we see these yellow lines of sodium, because the sodium atom is a partner in the molecule of salt. It so happens that each element sends out definite wireless messages in the form of lines, and these are read by their position in the spectrum, and in this way the

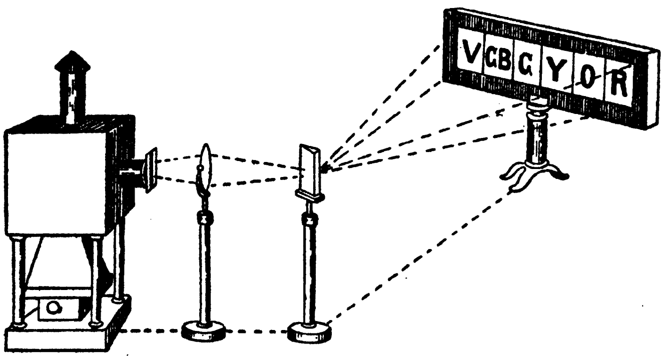


FIG. 50.—PRODUCING A SPECTRUM.

A beam of light is passed through a prism and the ether waves are bent, the amount of bending differing for different wave-lengths, thus spreading out the waves in a so-called spectrum.

various elements are detected, whether they happen to be in elementary substance or in compounds. It is well known that it is by the spectra of the sun and stars we are able to discover the elements present in them. It was in this way that Helium was discovered in the sun before it was found upon this planet Earth. Hence the name of the element from the Greek *helios*, sun.

These lines are seen because the ether waves

bombard our apparatus of vision; they may be photographed also by allowing them to bombard the chemicals on a photographic plate. Here are some of the characteristic lines produced by different elements.

It goes without saying that if these lines are due to vibrating electrons, and if we can control the vibration of the electrons, we should be able to alter the position of the lines in the spectrum of an element. This is what Zeeman did in 1896. He placed the incandescent substance in a powerful magnetic field, the effect of which would be to hasten some and retard others of the electrons, according to the position of the orbits in which the electrons were revolving. If an electron is made to vibrate quickly, it will give a line higher up the spectrum than when vibrating at the lower speed. Again, if the vibration be reduced by the magnetic field, the shift of the line will be towards the lower end of the spectrum. That is exactly what Zeeman was able to do.

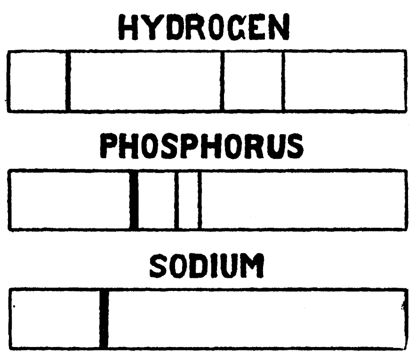


FIG. 51.—SPECTRA OF THREE WELL-KNOWN ELEMENTS.

There is no mystery about the magnetic field affecting moving electrons. This may be shown

by a very simple experiment. If we arrange a vacuum tube to show a luminous stream of electrons (cathode rays), we may very easily deflect the beam of particles by holding the pole of a magnet in the neighbourhood of the tube. The electrons will be deflected according to the magnetic pole to which they are exposed. In the case of the Zeeman effect, electrons moving in a circle have their speed increased or retarded.

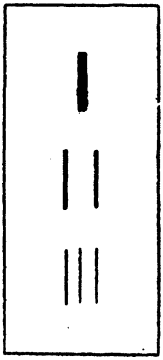


FIG. 52.—ZEEMAN EFFECT. Showing alteration of lines due to the application of a magnetic field to a flame.

I remember being very much impressed by the Zeeman experiment when I first saw it (shortly after the discovery) in the laboratory of Lord Blythswood at Renfrew. Before the magnetic field was applied, one saw the most marked lines of the yellow of sodium as a single line, as shown in the top line of Fig. 52. When the light was passed through the magnetic field (in the direction of the lines of force), two lines were seen, one nearer the red end and the other nearer the violet end. It is very impressive, if one realises that the movement of electrons are being controlled by the magnetic field.

When viewed at right angles to the lines of force, three lines were seen. The two positions of viewing are represented in Figs. 53 and 54.

NS represents the electro-magnet, the north

and south poles of which are marked *N* and *S*. The flame of the Bunsen burner is placed in the

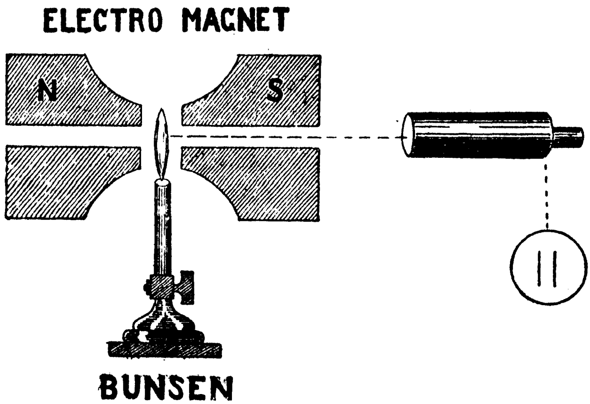


FIG. 53.—PRODUCING ZEEMAN EFFECT (2 LINES).
The electrons in a flame are disturbed by a magnetic field.

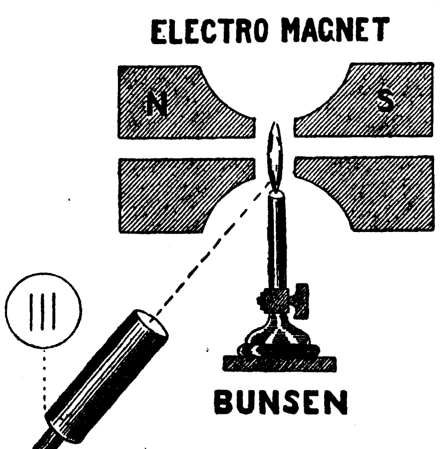


FIG. 54.—PRODUCING ZEEMAN EFFECT (3 LINES).
It will be observed that the spectroscope is placed in a different position from that in Fig. 53.

magnetic field, and when the spectroscope is placed as in the diagram two lines are seen.

When the spectroscope is placed as in Fig. 54, the three lines are seen.

The reason why only two lines are seen in the first case is because the vibrations taking place in the line of sight send no waves to the eye. If, however, we look across the field, as in Fig. 54, these vibrations, which had no effect, will now produce an effect; and as these are unaltered by the magnetic field, we see a line in the original position unaltered, and it is standing between the two new lines.

The appearance in the spectroscope or in a photograph is shown in Fig. 52.

This was not the first proof of a connection between magnetism and light. The Zeeman effect (1896) was discovered one year before the individual electron was discovered by Sir J. J. Thomson, but H. A. Lorentz (Amsterdam) had suggested the existence of minute particles revolving in atoms (and producing the ether waves of light). Lorentz put forward his theory in 1880, which was seventeen years before the electron was discovered. The Zeeman effect was a remarkable vindication of the Lorentzian theory.

So early as 1845, Michael Faraday was able to prove a connection between magnetism and light. He passed a beam of light from a lantern through a crystal which polarised the light. This polarised beam passed through a hole bored

through the core of a large electro-magnet as shown in Fig. 55.

On emerging from the magnet it passed through a second crystal, called an analyser, which was able to cut off the polarised light when turned with its axis at right angles to the first crystal, in which position the ether waves could not find a passage. The problem which Faraday set himself was in effect the following: Instead

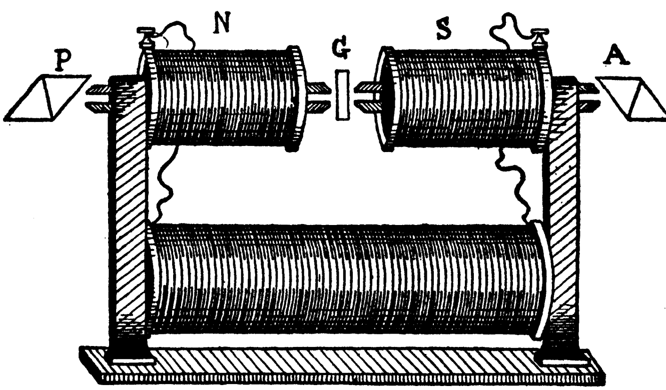


FIG. 55.—MAGNETISM AND LIGHT.

of completely turning round the crystal so that it cut off all the polarised beam, would it not be possible to rotate the beam into such a position that it could not get through the analyser? Faraday applied the magnetic field to *G*, whereupon the light was cut off; it failed to get through the second prism. The polariser's duty was to allow any ether waves in one plane to pass, and these polarised waves were free to pass through the second prism in the position in which it was

placed, but the magnetic field rotated the plane of the waves till their plane was such that they could not pass. We speak of the magnetic rotation of the plane of polarisation. This was no chance discovery made by Faraday; it was deliberately sought for. He rotated the plane of the waves as they passed through a piece of specially annealed glass (shown at *G* in the diagram, Fig. 55). So long as no magnetic field was applied, the polarised beam passed through the analyser, but when the magnet was energised, it produced a magnetic field, which rotated the plane of the ether waves of light.

It was twenty years after this discovery that Clerk-Maxwell may be said to have combined this phenomenon with the phenomenon of electro-magnetic induction, which Faraday had discovered in 1831, for it was in 1865 that Clerk-Maxwell put forward his historic theory of electro-magnetic waves, which, after Hertz's detection of long electro-magnetic waves, led on to the achievement of wireless telegraphy.

It is interesting to note that the shifting of spectrum lines gives us knowledge of the motion of stars in the line of sight; we find that some stars are approaching the Earth, while others are receding from it. In the case of the approaching stars, there is no immediate danger. One might take alarm; the Dog star is travelling in our direction with an enormous velocity, far greater than that of an express train. However, it is not moving directly towards the Earth, as it has

a transverse movement as well as a direct one. It may be observed that there is no cause for alarm ; even if it were approaching us directly our planet would not likely be here to receive the star.

The reader may be curious to know how we can tell that a star is approaching to or receding from us. It goes without saying that it is not by direct observation, for we are often puzzled to know whether such a large object as a motor-car on a road is approaching to or receding from us. It has been stated already that it is by means of the shift in the spectrum lines. But why should the lines shift in these cases ? This will be easily explained by considering a phenomenon known as *Doppler's Principle.*

We have a practical demonstration in the realm of sound which is analogous to that of the ether waves of light.

If one is standing near a railway track when a whistling engine passes, it is quite noticeable that as the train reaches the observer the pitch of the sound of the whistle drops the moment the engine has passed. It goes without saying that the engine is sending out sound waves of the same pitch all the time, but they appear to fall in pitch. Why ? Because as the engine rushes away from the observer, fewer air waves will arrive in each second of time, fewer than was the case when the engine was approaching. In receding, the engine places the waves very slightly farther apart. The lowering of the pitch is analogous to the shifting of the spectrum line towards the red end

of the spectrum. Therefore, if we see the pitch of a known line of starlight lowered in the spectrum, we know that the star is receding from us, and conversely a shifting of a line towards the violet end indicates that the star sending out the light is approaching us.

Range of Ether Waves

The whole gamut or scale of ether waves is shown in Fig. 56.

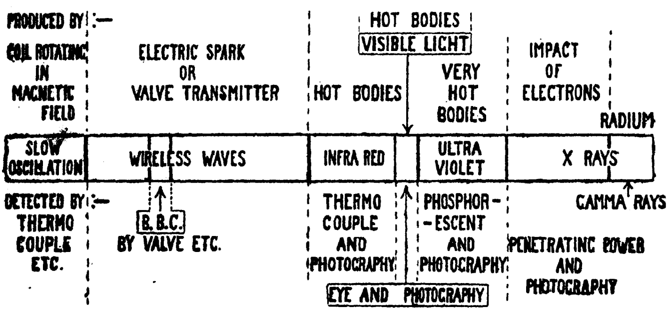
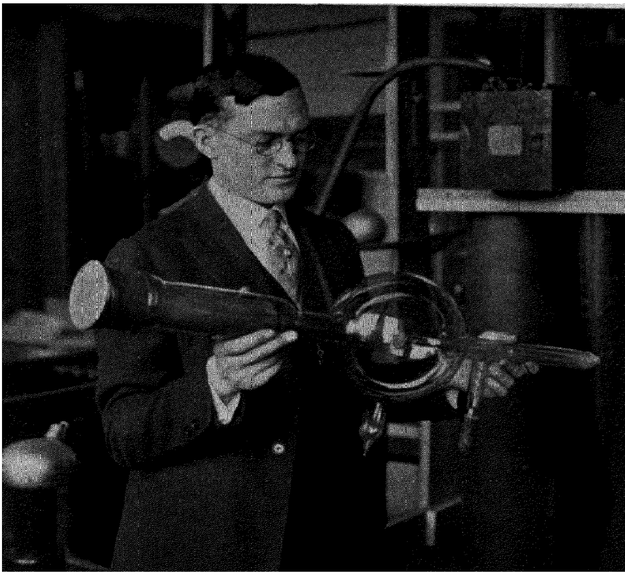


Fig. 56.—Octaves of Ether Waves.
This diagram shows how the waves are produced and how they are detected.

Waves due to comparatively slow electron oscillation. Such waves might be produced by a coil rotating in a magnetic field. This would set the electrons in the wire surging to and fro, and the vibrations of these electrons would produce electro-magnetic waves in the ether. Such waves are exceptionally long, and they measure very many miles from crest to crest.

The next section of long waves are those we use in wireless, and from the diagram it will



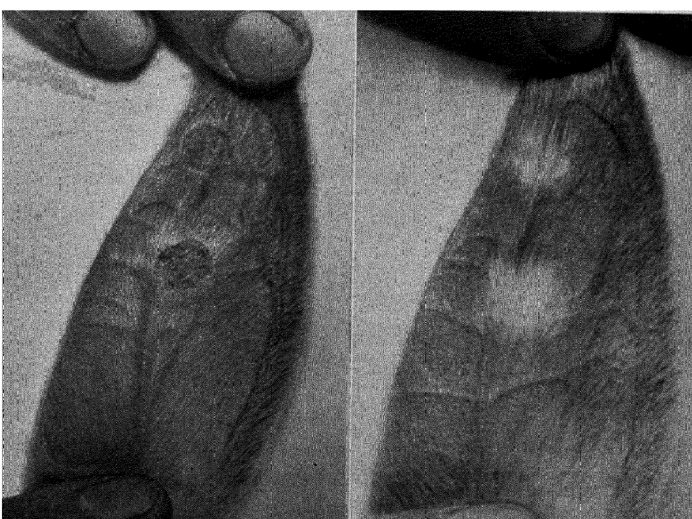


Photo *"Discovery"*

CURATIVE POWER OF X-RAYS

A Coolidge X-ray tube is shown in the upper illustration. When X-rays were applied to the sore on a rabbit's ear, the trouble was cured with an exposure of fifteen seconds.

be seen that only a very small portion of these (about the centre of section) are given to the British Broadcasting Corporation for their various stations. The first method of producing such waves was by the oscillations of electrons in a spark discharge, but this has been largely displaced by the invention of the thermionic valve used as a transmitter, and which we consider in another chapter.

Some of these waves have the crests of their waves 200 miles apart, and others only a few yards apart; while those given to the British Broadcasting Corporation vary from 546 yards to 328 yards. It is usual to state the Broadcasting waves in metres, and the method which the present author has adopted of stating the wave-length in miles, yards and inches is quite unorthodox, but he has thought that it would appeal to the layman who is more accustomed to using these measures. The scientific method is to reckon the wave-lengths in what are known as Angstrom units. One of these units is equivalent to $\frac{1}{10000000}$th part of a millimetre; wireless waves are measured in metres.

Some of the Herzian waves may become common in wireless work when the reflected beam has been developed and brought into practice, progress in which has already been made.

Some of the waves are called Herzian waves, after Hertz, who was the first to detect the presence of these electro-magnetic waves. The wireless and short Herzian waves are all included

under the title wireless waves. These waves are produced in the same way as the waves used in wireless, and they may be detected also in the same way, but the first detector was a simple hoop of wire with a spark gap as shown in Fig. 57.

There is an overlapping between the section of short Herzian waves and the next section of

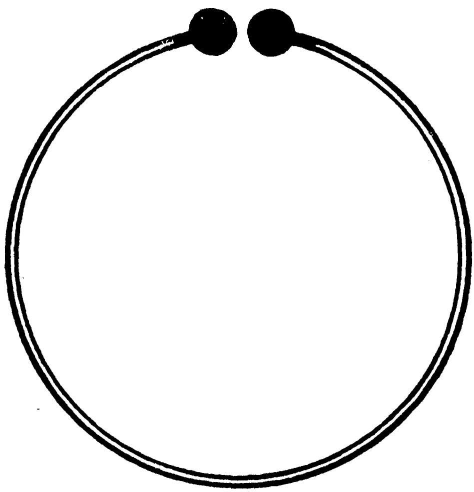


FIG. 57.—HERTZ WIRELESS DETECTOR.
Hertz discovered the electric waves by means of this simple detector.

infra-red rays, but this has been omitted in the diagram in order to simplify matters.

The infra-red rays occupy less of the scale than the Herzian waves but a great deal more than the visible light. These infra-red rays are really heat waves, and are produced by hot bodies.

The term *red hot* indicates the lowest degree

at which a body becomes incandescent. Every solid body, when heated, shows red as its first wireless message. It is only at a much higher temperature that the object becomes *white hot.* No body heated to incandescence ever shows the intermediate blue-producing waves, because these are superimposed on the previously existing red-producing waves, but as the temperature rises from dull red it is noticeably brighter when the yellow-producing waves are added, and by the time all the range of infra-red rays are produced the radiations are able to stimulate the sensation of white.

While the powers of the eye are very limited as to range of ether waves, some photographic plates have a very much wider range, being affected both by infra-red rays and also the other invisible rays, which are named ultra-violet light.

The infra-red rays may be detected by their heating effects of sensitive thermometers known as *Pyrometers* and *Bolometers,* as well as by the photo-chemical effects. The wave-lengths of infra-red rays is from about $\frac{1}{100}$th to $\frac{1}{30000}$th of an inch.

Solar radiation comprises part of the infra-red section, the whole of the visible light section and part of the ultra-violet section.

The section of visible light has been referred to in the preceding paragraph, and occupies a small space between the infra-red and the ultra-violet. The wave-length varies from about $\frac{1}{34000}$th to $\frac{1}{70000}$th of an inch.

The ultra-violet section is overlapped by the X-ray section to more than one-half, though not shown in the diagram. Thus ultra-violet rays are produced by very hot bodies. They also accompany the electric spark due to the surging of electrons. Not only can they be detected by their photo-chemical properties, but they will cause a phosphorescent screen or other phosphorescent body to shine. In addition to these, the ultra-violet rays have other chemical actions as well as being produced by ionised gases; they will cause ionisation. The ultra-violet waves may measure from $\frac{1}{70000}$th of an inch to $\frac{1}{2000000}$th of an inch.

The next section contains the well-known X-rays, which were discovered by Röntgen in 1895. Their method of production by a discharge within a vacuum tube is doubtless well known even to the layman. The waves measure, from crest to crest, from $\frac{1}{250000}$th part of an inch to $\frac{1}{15000000}$th part of an inch.

It is well known that these rays affect a fluorescent screen and a photographic plate. They also have a chemical action through the ether waves disturbing the electrons upon which they impinge, and their great penetrating power is also well known.

The Gamma rays are X-rays of higher pitch than we can produce in the laboratory. They are produced in Nature by radioactive substances such as Radium. Their wave-length may be as short as $\frac{1}{4500000000}$th of an inch, and

they are the shortest waves that have been detected.

As already stated, the proper scientific method of describing the wave-lengths is to use the Angstrom unit, but, in defence of the method adopted here for the layman, it may be pointed out that to state that the longest waves used in wireless are 300 billion units, does not enable the reader to visualise the size in the same way as the statement that the crests of the waves are about 200 miles apart.

CHAPTER XIII

TWO THEORIES THAT ARE DIFFICULT

EINSTEIN'S Theory of Relativity is known to the layman, and he may have heard of the Quantum Theory which preceded it, but he does not understand them, neither do many people who are keenly interested in Science. These theories are very difficult; they cannot be understood properly outside the domain of mathematics, and yet the general reader would like to know what all the noise is about. He will be satisfied with a glimpse at the meaning of these theories.

The Quantum Theory, as its name implies, has to do with quanta, or portions, and it is with the energy of radiation that it deals. It is a very strange idea to think of the energy of radiation, or, in other words, light, existing in individual quanta. It is difficult, indeed, for the layman to think of energy as being a thing *per se*, and to think of energy and matter as being interchangeable seems highly absurd, and yet we shall see that this idea is put forward for serious acceptance, and we shall see how it is supposed to come about that matter may become energy.

The Quantum Theory is based upon the work of Planck, which is purely mathematical. He dis-

covered a constant (something that does not change) in the mathematics of the radiation of energy ; he found that the energy was emitted in quanta, or particles, of energy ; that the energy was a constant number of times the frequency, or, in other words, Planck's constant, when multiplied by the frequency of vibration, gave the energy of one quantum.

When the present author was writing *Scientific Ideas of To-day*, in 1907, he did not include Planck's work, as it did not seem suitable then for the general reader. When that book was translated into Spanish, the translator, after remarking upon the difficulty of translating the dry, idiomatic phrases of the English into the more ornate language of the Spanish, drew attention to the omission of Planck, but said that probably the author feared that it might drive the reader mad. The case is not so desperate, and since the advent of the Theory of Relativity, the subject has become of more interest to the layman.

Planck's discovery, that energy is emitted in quanta, was made when considering the energy emitted by the radiation of a black body, or that emitted through a hole from an incandescent furnace ; it is called cavity radiation.

The theory of quanta accounted for the distribution of energy in the spectrum of cavity radiation, in which the maximum energy is in the infra-red part of the spectrum.

It was this that led up to the Quantum Theory ; Planck's constant explained many physical and

chemical phenomena. But what about these quanta of radiation or light?

We have become familiar with the idea of particles of electricity; we cannot doubt that electricity is atomic, and we have proof that all electrons are identical, as also are all protons, but not so with the quanta of light. The quanta differ in size, if we can think of size in connection with anything immaterial; we picture a quanta of blue light as larger than a quanta of green light, and as double the size of a quanta of red light—the larger quanta containing more energy. The largest of all is the X-ray radiation, it being of highest frequency, and the smallest quantities of energy—the smallest quanta—are the radiations of the lower end of the spectrum. But where do these quanta come from?

According to the Bohr Theory, which we have considered already, the jump of an electron from an outer to an inner ring causes a quanta of light to be emitted.

Picture an electron jumping right into the centre of the atom. Think what would happen in a simple atom, the hydrogen atom, which, as you know, consists of one electron circling round one proton forming the nucleus. That is the whole atom; the negative electron balances the positive proton, and they behave like the Moon and the Earth; the atom is a revolving system. Suppose the electron jumps into the proton, the atom will be destroyed; we picture a cancellation of the opposite electricities. The atom would

disappear in a flash of light; matter would become energy. Instead of complete annihilation there may be loss of atomic weight in changing from one atom to another. The Sun is losing mass at an enormous rate; millions of tons in every minute.

The same must be taking place in the great, and greater, Suns—the Stars—and this theory accounts for the presence of those very penetrating rays which Millikan and others have found arriving from space; may they not be due to this cancellation of electricities in the atoms composing the Stars; matter being radiated away in energy?

J. H. Jeans made an interesting statement in the Rouse Ball Lecture of 1925.

"Such an atomicity of energy almost certainly exists, and, although it does not show itself in laboratory experiments, it is, I believe, of fundamental importance in the economics of the universe. As a matter of astronomical observation, young stars have far greater masses than old stars. By methods which need not be detailed here, it is possible to estimate the age-difference between any two stars or types of stars, and the Stars' total radiation of energy in this period of time just about represents the observed difference in mass, provided the 'rate of exchange' is the value demanded by the Theory of Relativity."

When a body emits quanta of light, what happens? Are the quanta shot off like rifle bullets, and do they remain as such until absorbed by the atom upon which they fall? Or is it possible that

the quanta, when emitted, lose their individuality and spread out into ether waves, which are absorbed in definite quanta by the atom, causing an electron to jump to an outer ring ? Which is the truth we do not know.

By way of analogy, of energy existing in quanta, a curious piece of apparatus may be mentioned. My friend, Professor H. Stanley Allen, found a piece of apparatus in the laboratory in the University of St. Andrews, and this may be of interest in connection with the subject.

A wooden disc with a pair of projecting axles is placed upon a small step-ladder, and when the disc is left at rest it suddenly makes up its mind to move down a step; then after a considerable pause it moves again and again, making a prolonged pause at each step, as though its energy were in definite units. The secret of this behaviour is that there is a quantity of mercury hidden within the disc, and this mercury flows by gravitation from one chamber to another; the communication being a narrow orifice accounts for the apparent pauses. I have seen the disc in action, and it looks quite uncanny. An X-ray inspection discloses the secret.

Relativity

The Theory of Relativity, like the Quantum Theory, belongs to the domain of Mathematics; its ideas are extraordinarily difficult, and all that the layman can do is to get some general idea of what it is all about.

It is true that all our ideas of material things are relative. A pea is a very small thing relative to the Earth, but a very large thing relative to a microbe, and so on; but it is not the relativity of magnitude with which Einstein's theory deals.

It is obvious that our ideas of Time are also relative. A minute is a very long time if one has to sit still to have a photograph taken by artificial light, but it is infinitesimally small compared with a century, and so on.

Time plays an important part in the Theory of Relativity, and is spoken of as a fourth dimension, but we cannot think of Space in four dimensions, though we have to deal with time-space.

There are only three dimensions of Space itself; if we wish to define the position of a fish in a tank of water, we can state that the fish is 1 foot from the side of the tank, 2 feet from the end of the tank, and 3 feet from the bottom of the tank.

What Relativity says is that a length and an interval of time are relative to the observer. It may be helpful to consider the actual motion of a man as he walks about. We may say that he is moving with a velocity of 4 miles per hour; that is his velocity relative to the Earth, but we may say he has a velocity of 1000 miles per minute relative to the Sun, for he is being carried along the Earth's orbit around the Sun at that velocity. Then, again, there is the motion of the Solar System in space relative to the so-called fixed stars, which again are moving in two great streams. We see

that the motion of a man is a very complicated affair, and is relative to a number of moving things. The Theory of Relativity deals with Time and Space relative to the observer.

Before the advent of Einstein's theory, we thought of Time and Space as being entirely independent of the observer, and of all other things. We pictured them as always existing, and continuing to exist, whether or not we, and all material things, existed, or ceased to exist. The Relativity Theory has to dislodge these preconceived ideas, and therein is difficulty.

If Space and Time are to be the things which contain the universe, we must have means of measuring them. We can only measure Space by measuring from one material object to another, and we can only measure Time from one event to another, and these measurements must be relative to the observer ; a man on the Sun, if he could exist, would have quite a different view from a man on the Earth. There must be relativity ; an isolated object quite alone in space could not have velocity ; it would be meaningless to speak of its velocity unless we could relate it to some other object.

What the general reader really wishes to know is wherein does Einstein's theory become of practical value to Science.

An illustration of its utility may be taken from astronomical phenomena. According to Newton's laws of motion, a planet moves in an ellipse with the Sun in one focus, repeating the

same path in each revolution, so that the point where it is nearest the Sun has a certain motion in the inertial frame on which the Sun may be supposed to be at rest ; but Einstein's theory, concerning Relativity, comes to the rescue and gives another solution of the problem. Einstein says that the point where the planet is nearest to the Sun advances a small amount at every revolution, and this idea dispels what was previously a puzzle to astronomers in connection with the movements of the planet Mercury. There had been for a long time a discrepancy between calculation and observation of the motion of the point at which Mercury came nearest to the Sun. This point had been observed to advance a small amount (*forty-three seconds of arc per century*) beyond the amount it should, according to calculation, and this after allowing for the disturbing effect due to the presence of other planets. This discrepancy between calculation and observation was dispelled by Einstein's theory, which placed the planet where it was found to be.

Again, it is interesting to know that rays of light, though immaterial, are subject to gravitation, according to the Theory of Relativity. This has been proved to be the case, and the bending of light by gravitation may be seen in connection with astronomical matters, though we cannot make any such experiment in the laboratory.

The amount of bending due to gravitation has been calculated, and it is so small that in the case of light passing near the Moon there is no observ-

able distortion. The case is different with the Sun, owing to its great mass. We have evidence of light being bent by the gravitation of the Sun. Such observations can only be made during a total eclipse of the Sun, for the light of the Sun must be obscured to enable a photograph of the stars near the Sun to be taken.

In 1919 an eclipse expedition went out to Sobral, Brazil, another to Principe Island (African Coast), at both of which the Sun's eclipse was total in that year. Photographs were taken showing the position of stars when near to the Sun, and they appeared to have shifted from their normal, the apparent shift being due to the bending of light before it reached the photographic plate.

There is another point which puzzles the layman, and that is regarding a shrinkage in bodies due to their motion through the ether. In point of fact, this question is outside the subject of Relativity, but one often hears it mentioned in this connection, and the layman may wish to know if it is an established fact or only an idea. This shrinkage was suggested before the advent of Einstein's theory, and was first mentioned in a conversation between Fitzgerald and Lodge, when they were discussing the experiment of Michelson and Morley, with which we have dealt already.

In discussing this experiment, Fitzgerald said to Lodge:

"Well, I believe the thing which holds his mirrors (used in the experiment) shrinks when it

is moving. Light ought to take longer to go to and fro in one direction than in another direction, but the Michelson-Morley experiment said it took the same time. It requires longer time to move with the stream and up again than it takes to move to and fro across the stream."

Fitzgerald's suggestion was that the apparatus shrank, shortening the distance in the direction it should take longer to travel, and that this shrinkage accounted for the negative result of the experiment.

Soon afterwards, Lorentz of Leyden showed that, according to the electrical theory of matter, shrinkage ought to occur, and on calculating the amount of shrinkage which would take place, he found it to be exactly what was required to give a negative result in the Michelson-Morley experiment.

It was the perplexing negative result of this experiment which led Einstein to his general Theory of Relativity. It looked as though there was absolute motion in connection with light, whereas Newton's laws declare that absolute motion could not exist in any other branch of Physics. Theoretical Physics had to try and explain this difficulty between classical physics and experience. The real difficulty was that Newton had established the conception of absolute time. Einstein recognised that time was not absolute, but merely relative.

He said that all statements of time depend upon the standpoint of the observer who is

describing them. Another observer would describe it differently if the two observers are in motion relatively to each other.

There can be no absolute measure of time, so also can there be no absolute measure of length. If a rod has a definite length for an observer to whom the rod is relatively at rest, then the same rod will appear shorter to an observer who is moving relative to the first observer in the direction of the rod's length.

This change in size is believed in, but the layman's manner of expressing it is often grossly exaggerated. I have heard it said that when travelling in one direction a man is enormously larger than when passing through the ether in a direction at right angles to that, and that the only reason for not observing this great alteration is that everything else changes in similar fashion. The actual change is calculated as infinitesimally small, so small that it would be impossible to observe it even if one object alone altered in size.

In a body so large as the Earth the shrinkage might be 3 inches in 8000 miles, at one possible velocity, but the shrinkage would increase with the increase of velocity.

Einstein's theory can account for this apparent shrinkage without presuming physical change at all; it is due to the fact that one observer sees things differently from another moving observer; it is all a case of relativity.

Another puzzle to the layman is how it is that there can be no greater velocity than that of light.

The reason is that the ether will let that velocity pass through it but nothing greater.

Lodge gives us an analogy. In the ocean of air, sound has the velocity at which air will get out of its way. When dynamite explodes, the air declines to get out of the way. The air is made to get out of the way, but then material objects are made to get out of the way too. One resists as much as the other. The velocity of light is the velocity at which the ether will get out of the way, and consequently nothing can move quicker than that. That is a maximum velocity.

The velocity of light appears to be absolute.

What Einstein has done is to explain the Universe by pure mathematics, dispensing with the ether and with physics, but this is not very helpful to the layman who wishes to visualise things, and we have seen (page 18) that Einstein believes in the ether.

In trying to explain the Theory of Relativity and the Quantum Theory without mathematics, one is somewhat in the position of the Highlander who, when asked by another Highlander to explain the electric telegraph, said: "Man! I don't understand it, but I think I can explain it."

CHAPTER XIV

THE THERMIONIC VALVE

MOST laymen are familiar with the Thermionic Valve in Wireless Telephony, more especially as a receiver, but all may not be conversant with the why and wherefore of the valve.

It will be of interest to see how it came to be invented. It is well known that the inventor was Professor J. A. Fleming, of University College, London.

The real beginning came about by Edison placing a little metal plate within an electric incandescent glow-lamp. I was curious to know what he had in view in doing this, and he has told me that he was trying to discover some means of preventing the blackening of the carbon filament lamps.

One of the arrangements was as shown in Fig. 58.

When working with one of these specially arranged bulbs, Edison discovered in 1883 that there was a flow of electricity between the filament and the plate when he connected these as arranged in the diagram. Of course Edison thought of a positive current, as electrons were not discovered till after that date Edison pictured a positive

current flowing from the metallic plate to the filament, and passing through the galvanometer (*G*) on its way back to the plate. We know now that the current flows in the opposite direction, because it is in the opposite direction that the electrons make their march or drift. There would be a positive current in the opposite direction if the protons or positive particles were not securely anchored within the atoms.

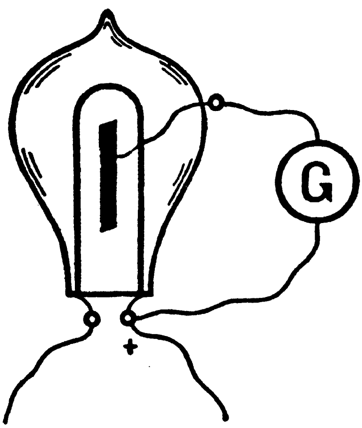


FIG. 58.—EDISON EFFECT.

Edison took out a patent for his arrangement of bulb, but he did not specify any practical purpose to which it might be put; it remained of scientific interest only.

Sir William Preece obtained some of these lamps from Edison, and Preece discovered that the *Edison Effect*, as it was called, increased very rapidly as the filament was raised to higher temperatures. We know the reason for this, since the advent of the Electron Theory; it is because the hotter the filament is the more electrons are dislodged from it; but, as already pointed out, they did not know that the electric current was due to a drift of electrons, or we might say due to the regular movement of electrons, so as to include the alternating current,

in which the electrons merely move to and fro from atom to atom.

Then Professor J. A. Fleming discovered that the Edison Effect or current might be stopped by placing a piece of mica between the filament and the plate. This fact seemed to indicate that there was some emission from the hot filament which was held up by the intervening mica.

Further experiments by Fleming showed that the hot filament was actually giving off a torrent of negative electricity, whatever that was thought to be; it was not considered a thing *per se.* Even ten years later a distinguished physicist said that he thought the word "electricity" would disappear and leave only such terms as "electrification."

Fleming was able to show that the plate became negatively charged, for when he connected it to a gold-leaf electroscope with a positive charge, the gold leaves were discharged, or, in other words, received the addition of a negative charge. In 1888 Fleming made his great discovery, which led to wireless telephony, and which has had far-reaching results in other branches.

The valve which he discovered makes an excellent relay for the electrical engineer, and has put a new implement of research in the hands of scientific investigators.

It has also greatly increased the distance of wireless telegraphy, and last, but not least, it does not confine itself to receiving and amplifying, but also gives us a most convenient form of transmitter,

It is interesting to note what led Fleming to seek to amplify the current. It is most unfortunate that he is almost stone deaf, but his very deafness led him towards his discovery. The telephone receiver had been introduced into wireless telegraphy for reading the Morse signals, and this was a great disadvantage to Fleming, who, as Professor of Electrical Engineering in University College, London, was very much interested in Wireless Telegraphy. It was his deafness that made him desire to so amplify the current that it might be possible to have a visible signal instead of an audible one. In discovering the valve he did not get rid of the telephone, but actually made speech possible by wireless.

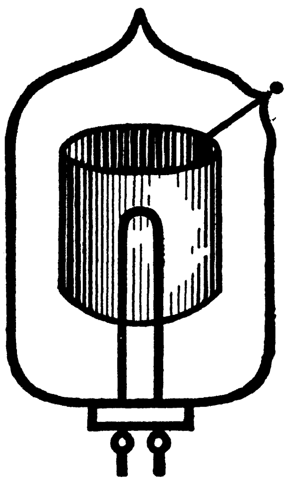


FIG. 59.—FLEMING VALVE. Fleming placed a circular plate around the filament.

Fleming arranged his lamp as in Fig. 59.

It will be observed that the metallic plate surrounds the filament so as to get a maximum effect, but what was Fleming's great discovery? That if he sent an electric current through the lamp it would travel in one direction only. Here was a means of converting an alternating current into a direct current, which act we speak of as rectifying the current.

Picture what happens when a stream of electrons passes from the filament to the plate; the plate will become charged with electrons which will repel any further drift, and so the way of the current becomes closed just as by a valve. The valve will be opened as soon as the plate is discharged. This action gave the lamp the name of *oscillating valve.*

We can see how it is impossible to send a current through the lamp in the opposite direction, for we are trying to send a drift of electrons in opposition to the stream of electrons from the filament to the plate.

It is impossible to visualise the myriad of electrons taking part in the drift which forms a current of even 1 ampere (rate of flow). Here is the number put down in figures—6,250,000,000,000,000,000 per second. In words, it reads six and a quarter trillions, and if we picture the tank of a billion peas as described elsewhere, we have to multiply the thirty thousand years (required to empty it) by one million, making thirty billion (30,000,000,000) years to empty a tank of one trillion peas. The whole affair becomes unthinkable; we cannot visualise 6¼ trillion electrons moving in a conductor carrying 1 ampere of current.

To return to our consideration of the valve. An important addition was made to Fleming's valve by Dr. Lee de Forest (U.S.A.). He claimed in the American Courts that his was a new invention, but the Courts decided in favour of Professor

Fleming, and pointed out that it was merely an improvement.

What de Forest did was to place a gauze grid between the filament and the plate, as is shown in Fig. 60.

This addition was made by de Forest in 1907, and it was a most valuable addition. Let us picture what happens.

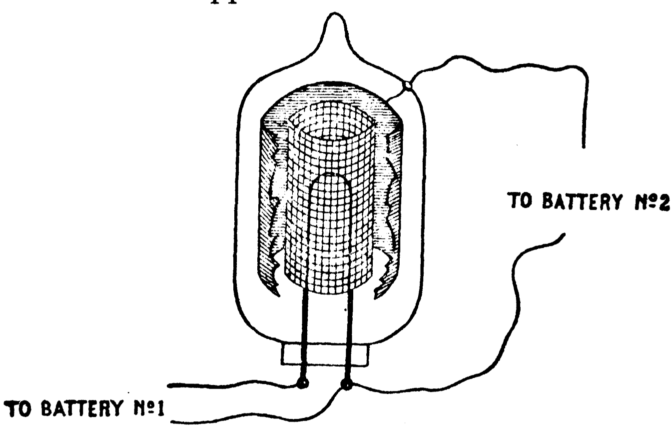


FIG. 60.—VALVE WITH GRID.
Lee de Forest added the metallic grid between the plate and the filament.

The electrons escaping from the incandescent filament congregate on the gauze grid and block the way of the current, which is being sent through the valve. It is well known to all that the filament is rendered incandescent by the passage of a low-pressure battery, whereas the current, being sent through the valve, is obtained from a high-voltage (pressure) battery.

Picture the obstructing grid connected to a wireless receiving aerial. When the ether waves

arrive at the aerial they cause the electrons in the aerial to surge to and fro, and the electrons in the grid will follow suit, so that there will be an opening and closing of the valve. In this way the valve may act as a detector of wireless signals, and also as a relay. A weak current may operate the valve and open and close a second valve, allowing a greater current to pass, and so on through a cascade of valves, until the current is amplified to the desired extent.

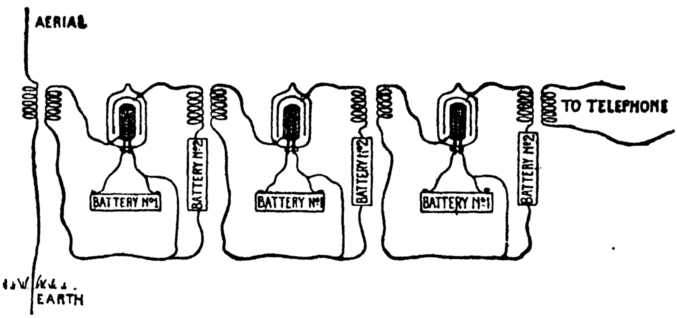


FIG. 61.—CASCADE OF VALVES.
Showing how the current is amplified.

In Fig. 61 is shown a cascade of valves.

In an attempt to make the matter clearer, I have given each valve a pair of batteries for itself, whereas in practice there is only needed one low-tension and one high-tension battery.

A valve may be connected to an aerial, and arranged to operate a telephone ; in this case the aerial is not connected directly to the valve, nor is the valve connected directly to the telephone. The connection is inductive ; the electrons in the aerial disturb the surrounding ether, and the

ether disturbance sets in motion the electrons in the valve circuit, and so on.

Again, the to-and-fro movement of the electrons in the transmitting aerial do not provide the energy for carrying the speech, but merely modulate a carrier wave as shown in Fig. 62.

The top line shows the high-frequency wave pro-

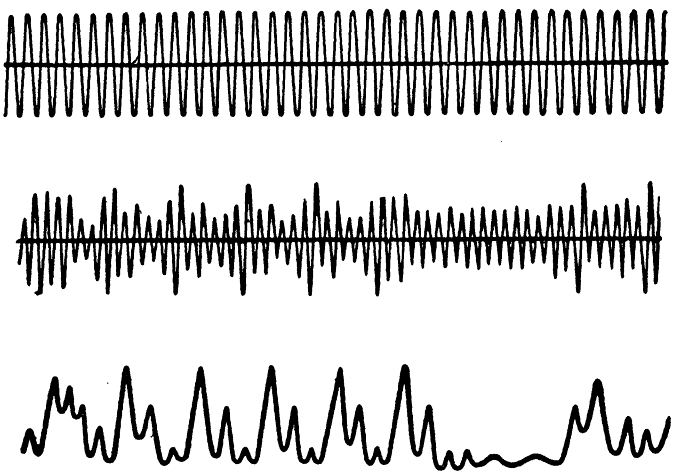


FIG. 62.—CARRIER WAVE.
The top line shows the high-frequency wave. The second line shows the modulation by the voice. The third line shows the current rectified.

duced by a dynamo and a valve transmitter. The second line shows the modulation of the electric wave acting under the influence of the voice, while the third line shows the rectification of that wave.

The subject is dealt with more fully in *Wireless of To-day*.[1] It only remains here to show how the thermionic valve may act as a transmitter.

[1] *Wireless of To-Day*, by Charles R. Gibson and W. B. Cole. Seeley, Service & Co. Ltd. (Science of To-Day Series.)

Fig. 63 shows how the valve is arranged to form a transmitter to produce ether waves.

It will be observed that the high-voltage current which passes to the plate goes through a primary coil. The secondary coil is wound over

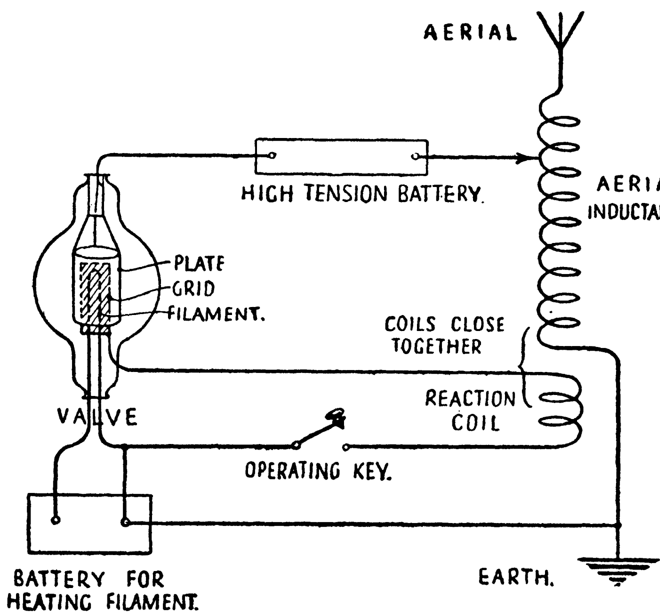


FIG. 63.—VALVE FOR TRANSMITTING.
The valve is used as a transmitter as well as a detector.

the top of the primary, and this secondary coil connects the grid and filament.

Connections are arranged so that any increase in the plate current will give the grid a negative charge, and this will, of course, hold up the plate current. But the reduction in the plate current will open the valve by giving the grid a positive

charge, and the result will be to increase the plate current.

The holding up and setting free of the plate current will be continuous, and the grid will act like the escapement wheel of a clock, the high voltage battery in the plate current being analogous to the clock spring.

These oscillations of electrons provide an excellent method of originating waves in the surrounding ether of space, and so we have the valve as a transmitter.

The microphone into which the speaker talks may be placed either in the grid or in the plate current. Although not dealing with the subject of wireless telephony, apart from the action of the electrons, I should like to draw attention to what has always appealed to me as the greatest marvel in telephony; the fact that a little metal disc can reproduce the speech of a distant friend so perfectly, that the friend's voice may be recognised by the imitations of the disc.

I was very much interested to witness the action of the condenser telephone in the University of Glasgow; the instrument having been developed by Dr. George Green. Large sheets of metallic paper sang and spoke most excellently under the influence of the ether waves arriving from the local broadcasting station and from London. These metallic sheets were hanging quite freely, and gave wonderfully pure tones. I merely mention the matter here, as the marvel of these vibrations appeals to me very much.

CHAPTER XV

TERRESTRIAL MAGNETISM

It was Dr. William Gilbert who first pointed out that the Earth is a magnet, and that it is because of the magnetic poles of the Earth that a freely moving magnet takes up its definite position. That was in or about the year 1600.

We have seen that magnetism is due to the motion of electrons, so we have to picture movements of electrons in the Earth. Where? In the crust or in the interior. It has been stated by some that the interior of the Earth is a core of iron, this conclusion being arrived at from its density and also from the behaviour of earthquakes. One might suppose on first thoughts that this iron centre would play a conspicuous part in the magnetism of the Earth. But remembering that the magnetism of a steel magnet may be destroyed by heat, and knowing that the internal temperature of the Earth is calculated to be something enormous at the centre, and that we have not to go far into the interior to reach a million degrees, we cannot imagine the supposed iron core to play a part. It seems evident that the regular forward movement of electrons must be in the crust of the Earth.

The vibratory movement of molecules in the interior of the Sun is calculated to be at the enormous speed of about 100 miles per second. These figures were given by Professor Eddington in one of his Gifford Lectures, and he said :

"That was the kind of speed to which an astronomer was accustomed in observing stars, planets and meteors ; so he naturally considered 40,000,000 degrees a very comfortable sort of condition to deal with. And if the astronomer was not frightened by it, the experimental physicist was quite contemptuous of it, for he was used to handling atoms shot off from Radium at 10,000 miles per second. He thought these jog-trot atoms in the stars very commonplace."

In our mental picture of the Earth's magnetism we see a magnetic field in the surrounding ether, due to the movement of electrons in the crust of the Earth, and it is this disturbed ether which moves our compass needles.

We have a grand demonstration of the magnetic field in the phenomena of Aurora.

The Aurora is due to a discharge of electrons from the Sun, and this vast stream of electrons will be deflected by a magnet, as we have seen already in the laboratory. And so it is that on nearing the Earth, the stream of electrons is deflected towards the poles of the Earth, giving us the great displays of Auroræ in the polar regions.

We picture the electron stream being greatest over the equatorial region of the Earth where the Earth is directly exposed to the stream,

which is caught by the magnetic lines of force and is consequently deflected, coming lower and lower down into the atmosphere as it approaches the poles. When it reaches a point where the rarity of the air is similar to that in a vacuum tube, it produces the same effect as that produced in a vacuum by a stream of cathode rays, which we know to be a stream of electrons shot off from the cathode or negative electrode.

Because of all this we feel sure that there is a connection between the Earth's magnetic field and the Auroræ, and since they are both influenced by the Sun, they should be related. This we know to be the case, for there is an observed relationship between the outbursts of spots on the Sun and the maxima of Auroræ.

We picture magnetic lines of force from pole to pole, and how far away from the Earth these may extend we do not know.

Professor Dolbear (U.S.A.), writing in 1903, in connection with earth currents, says:

"There is good reason for thinking that the other members of the Solar System are magnets . . . if that be the case they are all moving in each other's magnetic fields. As the movement of a conductor in a magnetic field produces an electric current in the conductor, and as what are known as earth currents, apparently due to some extra-terrestrial source, are well known, their origin is accounted for."

We are not concerned with the dip of the magnetic needle, nor with the fact that the

magnetic North Pole is not the geographical North Pole of the Earth; what we are interested in is the action of the electrons and the behaviour of the magnetism due to the electrons. This takes us into the subject of magnetic storms, which, like the Auroræ, bear a relationship to the sun-spots.

When sun-spots were first observed, the observations were discredited, because Aristotle had not mentioned them; they were put down to faults in the newly invented telescope.

Occasionally sun-spots are large enough to be seen with the unaided eye when protected by a dark glass, or during fog. Their actual size is enormous; one spot could swallow up many planets the size of the earth. The sun-spots or holes in the photosphere keep changing, and it was observed in 1852 that there was a maximum about every eleven years. We believe that great quantities of electrons are poured forth from these sun-spots, and this would account for the appearance of a maximum of Auroræ every eleven years; there is also a maximum of magnetic storms. The magnetic field of the Earth varies greatly from place to place on the Earth's surface, and also varies with time at any one place. The variations which occur at a definite fixed place are of two classes. Some are of a regular periodic character, while others are irregular, both as regards time of occurrence and their nature.

The regular variations have periods of one day, one month, one year, and also some longer periods.

It is the irregular variations which are called *magnetic storms.*

The magnetic field of the Earth is investigated by means of delicate apparatus known as magnetometers. These are not necessary to detect the presence of a magnetic storm, for such storms often upset the much clumsier pieces of apparatus used in ordinary telegraphy.

If the magnetic storm be due either to external magnetic or electric action, the only body which is at all likely to be concerned in such action is the Sun.

Magnetic storms are irregular in their occurrence, yet they show a well-marked periodicity, their frequency and their intensity increasing and decreasing together with a period of about eleven years. It will be observed that this corresponds with the periodicity of sun-spots already mentioned.

As already indicated, it seems clear that the magnetic storms are in some way due to the Sun, and in particular to sun-spots. Not only are magnetic storms at a maximum during a sun-spot maximum, but isolated storms of great intensity are frequently associated with the transit of a sun-spot or spots over the Sun's central meridian.

From calculation it is found that it cannot be a direct magnetic action, as supposed by one theory; the action is far too feeble to account for even the mildest magnetic storms.

Then as to electrical effects. We have seen in an earlier chapter that negative ions (atoms

which have gained an electron) have the property of condensing gases upon them, and we know that such ions are present in the Sun, and we know also that electrons are shot out into space. Whatever theory we choose to adopt, we are forced to the conclusion that the Sun is radiating an immense amount of energy during the occurrence of a magnetic storm. Lord Kelvin calculated that during one—not an exceptional—storm, the Sun had radiated in eight hours as much energy as it usually radiated in four months, and even this was not a severe storm.

The conclusion come to is that the manifestations of solar activity are not the direct, but the indirect cause of magnetic storms on the Earth. Their effect is like that of catalysis in Chemistry, a sort of trigger action ; they set in operation electric forces which already exist in the upper atmosphere. The energy of the storm is really terrestrial, but is set free by the action of the Sun.

Atmospheric Electricity

It was recognised long ago that the atmosphere was in a state of electrification. This was apparent as soon as it was recognised that lightning was really a huge electric spark. This had been suggested some time before Benjamin Franklin's famous experiment with the kite, but no proof had been obtained. Many experimenters set up iron rods to collect the atmospheric electricity ; one Russian experimenter lost his life through the discharge of electricity from one of

these rods. It is interesting to note that in order to provide an alarm telling when these rods became charged, Franklin invented those electrical chimes so commonly used in the days of statical electric machines.

It was soon recognised that electricity in the upper regions of the air is not confined to thunder-clouds, but could be detected at all times. One early method of detecting this was to shoot an arrow upwards, and to attach to it a thread with a ring at the free end. The ring was in contact with the plate of a gold-leaf electroscope. As the arrow ascended higher the gold leaves diverged more and more with electricity of the same kind as that overhead. One of Lord Kelvin's inventions was a water-dropper for detecting the electrical conditions of the atmosphere. An insulated vessel dropped water, and this action kept it electrified at the potential of the surrounding air, and a reading of this was obtained, and, if desired, a record could be made on a photographic paper.

Our present interest lies in the action of the electrons in the atmosphere. In the laboratory we may shoot electrons through the very rarified air of a vacuum tube, and these dislodge electrons from the atoms of gas, leaving atoms minus electrons. We call these ions. The same phenomenon will happen when the stream of electrons from the Sun enters the rarified atmosphere: the air will become ionised. These ions provide the nuclei for the condensation of clouds, just as we have seen in the C. T. R. Wilson apparatus.

After what we have already seen about sun-spots and Auroræ, we will not find it difficult to believe that cloud formation in the upper air is affected by the advent of Auroræ.

Away outside of our atmosphere the stream of electrons may impinge upon and pass through a comet's tail, and also the great nebulæ, both of which are composed of gases; and it is this impact or bombardment which causes these great objects to shine as they do, on the same principle as that of a vacuum tube.

The loss of electrons from the Earth will be added to the atmosphere. The loss is estimated as being equivalent to an electric current of 1000 ampères. It is a strange thought that this loss would deplete the Earth of its total charge in twelve minutes if there was no addition made to the Earth's charge, so it looks as though the stream of electrons from the Sun balanced this.

Rain, no doubt, plays an important part in the interchange of charge between the Earth and the atmosphere. It is evident that lightning is another vehicle of charge between the air and the Earth.

Those who are interested in wireless telegraphy and telephony know something of the *Heaviside Layer* which exists in the upper atmosphere, and which reflects the waves down to Earth again. This layer has also an important effect upon the charge in clouds; we picture it as a conducting layer. The most direct evidence we have of the real existence of this layer is afforded by Auroræ and magnetic storms.

CHAPTER XVI

THE SPECTROSCOPE

ALTHOUGH Newton was not the first to observe the spectrum of white light, which we know now to be the spreading out of the ether waves of various wave-lengths, he was the first to investigate the phenomenon.

His apparatus was very simple: he allowed a beam of sunlight to enter a dark room through a hole in a shutter—not a straight slit, but a round hole. Then he placed a glass prism in the path of the beam, and arranged the position of a screen so that the light, having passed through a prism, would fall upon the screen. Newton does suggest a slot, of which he gives measurements.

This simple arrangement forms the basis of the spectroscope, in which the light passes through a tube, after passing through a shutter having a very narrow slot or slit on the end of the tube; the breadth of the slot is adjustable. The prism is carried on a table so arranged that it may be turned round in order to alter the position of the prism. The light leaves the tube through a convex lens, which focuses the light into a parallel beam. It passes through the prism, which does the desired spreading out of the

various wave-lengths, and it enters a telescope, through which it is viewed, or through which a photograph may be taken. It will be understood that the lines which are seen or photographed are images of the slit through which the light passed on entering the first tube.

The spectroscope may be used for examining not only the light of the Sun and Stars, but the light from any source, such as a flame, or an incandescent substance, or the glow produced by the bombardment of the rarefied gases in vacuum tube.

If the source of light be a flame, with a small quantity of common salt in it, we see the lines which represent the element sodium; or better still, if we use a small quantity of fused salt, we see a yellow light forming a single line, which always appears in a definite position in the spectrum, its position being according to its wave-length.

It will be understood that when we examine an incandescent substance, there will be a continuous spectrum, just as in the solar spectrum.

What about the dark lines appearing in the continuous spectrum of solar light? These dark lines represent absentees, wave-lengths which have been absorbed by the light passing through cooler layers surrounding the incandescent body, and containing elements which are capable of originating these particular wave-lengths, and are capable also of absorbing them.

Here we see the electron-jumps from one ring to another ring within the atom, and the

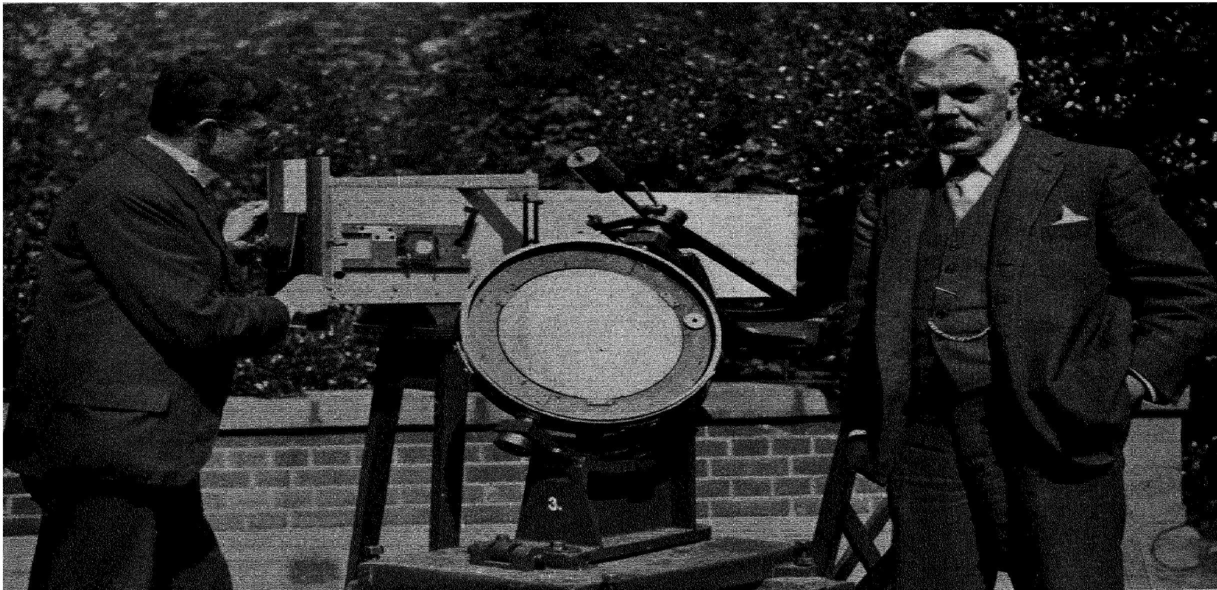


Photo *Special Press*

SOLAR ECLIPSE SPECTROSCOPE

The special spectroscope used by the Staff of the Royal Observatory in connection with the Solar Eclipse of 1927. The Astronomer Royal (Sir Frank Dyson, F.R.S.) is standing on the right. The concave mirror seen in front of the apparatus sends the light from the sun to another distant concave mirror, which reflects an image of the sun on to the slit of the spectroscope. The light, passing through the slit, and then through a prism, produces the lines of the spectrum on the camera screen or photographic plate.

capability of reversing the jump when energy is absorbed.

Newton did not observe lines ; the dark lines were discovered by Fraunhofer, and were called after him, but it was Sir George Gabriel Stokes who explained them.

When we speak of cooler gases absorbing the waves, we do not necessarily mean a cool gas, for the envelope of the Sun which absorbs the waves coming from the interior is by no means cool, yet it is much cooler than the millions of degrees of the interior of the Sun.

Again, the dark lines thus produced are only dark by comparison, for if the bright parts of the spectrum be well covered or screened, the dark lines are seen to be composed of very faint light.

The dark lines may be produced in the laboratory by passing the white light from an incandescent body through the flame of a spirit-lamp.

We know how an unknown element was discovered in the Sun by Lockyer observing unknown lines in the spectrum of the Sun—the now well-known element, Helium.

The prism of the spectroscope may be replaced by a ruled grating, which spreads out the ether waves in the same manner, and is called a difraction grating. Often, it is not a transparent but an opaque substance, such as speculum metal. The lines are scratched with a diamond, and this spoils the smooth surface and prevents reflections from these lines, while the spaces between the

scratches diffract the light, producing a series of spectra.

Usually these ether disturbance or waves interfere with one another as they spread out, and no light is seen, but, at one particular angle, they all arrive in the same phase. These parallel rays reinforce one another when brought to a focus by a lens, and a bright line (image of the slit) is produced, where each path differs from the next by one complete wave-length.

Many years ago I saw the machine for ruling these gratings which Lord Blythswood erected in his laboratory in Renfrew, Scotland. He had a special building erected for the machine. It was before the days of electric radiators, and I remember that the room was heated by a series of gas stoves, each under the automatic control of a thermostat, which turned down the gas, and cut it off altogether when the temperature reached a certain point, re-lighting it by a pilot jet when the temperature fell to a certain point again. Then he had near the ceiling some large wheels taken from the old-style bicycles, and these wheels had pieces of metal plate attached to them to act as fans, so that the air of the room would be well mixed by a rotation of the wheels.

To prevent any possibility of the small changes of temperature affecting the dividing engine which cut the lines on the speculum plate, the machine was enclosed within a large wooden box or chamber, having double walls with an interlining of cotton wool. A rise of temperature would expand

the levers of the machine sufficient to spoil the accuracy. The machine scratched the lines on the metal by means of a diamond, and there were as many as fourteen thousand lines per inch. I remember Lord Blythswood saying that it was equivalent to ruling fourteen lines on the cut edge of a piece of tissue paper.

Diffraction gratings have been ruled with twice the normal number of lines, which gives twenty-eight thousand lines to the inch, and these are for use when high revolving power is required, and for the study of shorter wave-lengths.

The colours are produced by the extinction of some of the wave-lengths, and leaving the others to stimulate the sensations which they are capable of producing.

By a special arrangement of apparatus, the spectrum of the light may be projected on to a screen, when blanks or darkness will be seen at the points which represent the missing waves.

The Polariscope

We have considered the analogy of water waves to represent ether waves; they are both transverse waves vibrating at right angles to their line of travel, but the water waves occur on the surface of the water, whereas there is no surface of the ether.

The motion of the water particles may be described as forming a perpendicular circle; the motion of the ether waves may be in every possible

plane within the ether, as has been pointed out already while dealing with ether waves. The reason for referring to the matter again is because the polariscope is an instrument for cutting off all the waves excepting those in the same plane.

In 1808, A. Malus (France) was looking through a crystal of Iceland spar, when on looking at the Luxembourg Palace, which was directly opposite his house, he saw an image of the setting sun reflected by the windows of the palace. As is well known, the Iceland spar produces a double image, and Malus expected to see two suns, but he saw only one; and to his further surprise, when he turned the crystal one quarter of a revolution, this one image disappeared, while the previous image appeared. Being a scientist, this was of great interest to him, and so he followed up his discovery, and in doing so he laid the foundation of a new branch of optics, to which the name of "Polarisation" was given. The name puzzled Fresnel, who wrote to a friend asking to send him some books which would explain the meaning of the polarisation of light, but it was left to Fresnel himself to solve the matter, which he did within a year from the date of his letter.

The Polariscope was the outcome of the accidental discovery made by Malus. He made up an analyser and a polariser for use with reflected light; but another form of polariscope deals with the refraction of light by means of crystals.

The crystal through which the light passes

first is called the analyser, and the second crystal is called the polariser. The crystal is made of that semi-transparent mineral named *Tourmaline*. It is cut into slices by sections parallel to its axis. When two such slices are placed one upon the other, as in Fig. 64(*A*), they form an opaque combination; no light can pass through the combined parts. *B* in the figure shows how the pieces were placed in an inclined position; the opaque position is at right angles to each other.

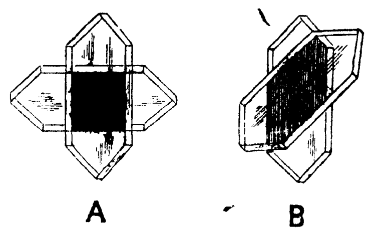


FIG. 64.—CRYSTALS IN POLARISCOPE. The left hand figure (*A*) shows the polarised light cut off. *B*. shows how the slices of crystal were placed in the crystal.

It is not necessary that the slices be cut from the same crystal, for all crystals of the substance must have the same pattern of construction.

By such means as described all the ether waves of light are prevented passing through. The explanation is that, on passing through the analyser, the light emerging from it has all its waves in the one plane; none other can pass.

The second crystal, the analyser, would let this light pass through if the crystal were placed in the same position as the first; but if the analyser is turned round one quarter revolution, as at *A*, this light is cut off. This is a test that the light passing through the first crystal is polarised, as otherwise this would not happen. As already

explained, by *polarised light* we mean light with its waves all in one plane, and not in various planes, as is the case with ordinary light.

Some beautiful colour phenomena may be produced by polarised light passing light through sheets of mica, etc., of various thicknesses, but our present interest is in the instrument.

CHAPTER XVII

THE EVOLUTION OF ELECTRICAL KNOWLEDGE

PART of the evolution of electrical knowledge has been dealt with in an early chapter, but it may be of interest to take a bird's-eye view of the whole subject.

Taking the practical side first, we commence with the rubbed amber phenomenon, not that it was put to any practical purpose, but because it was the first electrical experiment ever made, and also because in course of time it led to the invention of simple electric machines. The rubbed amber phenomenon is recorded by one of the seven wise men of Greece as early as 600 B.C. It was known also to the ancients that jet acted in the same manner as amber.

It is strange that it was possible for these two substances to reign supreme for more than two thousand years as the sole possessors of this attractive power, while so many common objects were ready to show the same phenomenon. The explanation is that the people of those days preferred philosophy to experiment, deeming experiments beneath their dignity.

Not till about the year 1600 did any one try

if other substances would behave in the same manner. Then one of Queen Elizabeth's physicians, Dr. Wm. Gilbert, found that glass, sulphur, resin and many other substances acted in the same way as amber.

In 1680, people made simple machines to do the rubbing on a larger scale than could be done by holding the substance in one hand and the rubber in the other. The first machine was

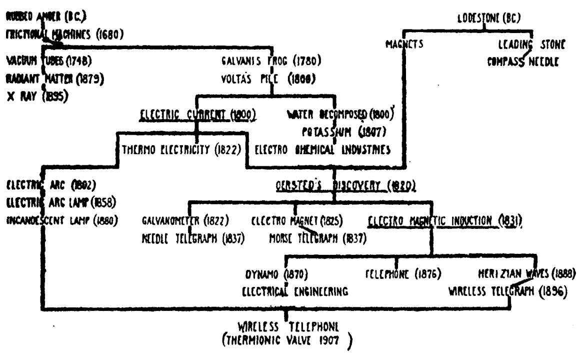


FIG. 65.

simply a ball of sulphur mounted on a spindle to which was attached a handle so that the ball could be revolved while the hand was pressed against it to produce the friction. Then followed glass cylinders and glass plates with cushions as the rubbers, and from these were evolved the modern influence machines in which there is no actual friction.

In 1748 it was discovered that the electric discharge from these machines would produce a beautiful glow when passed through a tube from

which the air had been pumped. It had been observed at a much earlier day that when a globe of rarefied air was electrified there was a luminosity within the globe.

Vacuum tubes remained as interesting experiments until 1879, when Sir William Crookes suggested that they contained what he called *radiant matter*, which we shall consider later, and which we know now to be a discharge of particles of negative electricity shot across the vacuum within the tube. It was when working with one of these vacuum tubes that Roentgen discovered X-rays in 1895.

Electric machines led indirectly to the discovery of the electric current in 1800.

An electric discharge may be pictured as a wild rush of an accumulation of particles of electricity along the conductor, while we picture the electric current as a steady progression of these particles.

The first step towards the discovery of the electric current was made in 1780, in the laboratory of Galvani, a Professor of Anatomy in Italy. His historical experiment with a frog has been related already in an earlier chapter.

Another Italian, Volta, who was a Professor of Natural Philosophy, could not accept this idea of the electricity being inherent in the animal, and he suggested that the electricity resided in the two dissimilar metals, and that there was a discharge between them when they were placed in contact.

In the spring of 1800, Volta made a pile of

metal discs of dissimilar metals, zinc and copper. Instead of using the moist flesh of the frog, he used pieces of cloth moistened in acidulated water. The method of building up the pile was as follows: a disc of zinc and a disc of copper, then a piece of the moist cloth, another couple of discs, and another cloth, and so on.

Volta found that when he connected the top disc of copper to the bottom disc of zinc there was a flow of electricity from the copper to the zinc. The frog was left out in the cold; its function had been merely that of an indicator.

It was an easy step from the pile with its moist cloths to the placing of the two metals in a vessel filled with acidulated water. Probably it was suggested by the cloths in the pile drying up quickly. In any case, this was the invention of the electric battery and the principle upon which all primary batteries have been made.

An important discovery was made by two Englishmen when working with the very first voltaic pile made in this country. When experimenting with this it was observed that the electric current had a chemical effect, to which the name of *electrolysis* was given at a later date.

Seven years after the discovery that a liquid could be decomposed by the passage of an electric current, it was discovered that solids could be decomposed in the same way. This discovery was made by Humphry Davy, when working in his laboratory in the Royal Institution, London, in 1807. He applied the current from his large

battery to a piece of potash, and he isolated the metal potassium, which was then seen for the first time. Up to that time the element had always been locked up in compounds. These discoveries form the basis of the Electro-chemical Industries of to-day.

Now we wish, for a moment, to go back again to a period before the Christian Era, in order to trace the beginning of our knowledge of magnetism. This was the discovery of lodestone, or natural magnet. It is magnetised iron ore found in some parts of the Earth, and first found in Asia Minor, at Magnesia ; hence the name magnet.

It was discovered by the ancients that a piece of lodestone, if freely suspended, would always come to rest in a definite position, pointing North and South, and they made use of this phenomenon by mounting a piece of lodestone in the hand of a small revolving figure, which guided their caravans across the trackless deserts. The compass needle was a natural evolution of this. It was Gilbert who suggested that the Earth itself is a magnet, and therefore attracts the ends of the compass needle so that it takes up its definite position.

It was discovered by the ancients that the attractive power of lodestone could be *apparently* passed on to pieces of iron by merely stroking them with the lodestone, and yet the lodestone lost nothing. We shall see what actually takes place when we consider the theoretical side.

As early as 1731, there were indications that there was a connection between Electricity and

Magnetism. I quote the following from the *Philosophical Transactions*, 1735, vol. xxxix. p. 74:

"A tradesman of Wakefield, having put up a great number of knives and forks in a large box, and having placed the box in the corner of a room, there happened a sudden storm of thunder and lightning, by which the corner of the room was damaged, the box split, and a good many knives and forks melted. The owner, emptying the box upon the counter, where some nails lay, the persons who took up the knives observed that the knives took up the nails." Lightning had magnetised the steel knives.

In 1751, Franklin succeeded in magnetising a sewing needle by means of the discharge of an electric machine, but the crowning discovery was made in 1820 by a Danish professor, Hans Christian Oersted. This was twenty years after the discovery of the electric current. This discovery was not accidental, as is often supposed, for Oersted announced in 1807 his intention of examining the action of electricity on the magnetic needle. We have seen how he discovered that a magnetic needle was influenced by a neighbouring electric current, so that the needle turned round at right angles to the conductor. A very simple discovery, but it forms the basis of almost all the practical applications of electricity, and is the foundation stone of Electrical Engineering.

Within two years of Oersted's discovery, a practical galvanometer was invented. In this the magnetic needle is placed within a coil of

wire, and the needle may be in a horizontal or in a vertical position; it is a slight variation of Oersted's experiment.

It was a simple step from that to the single needle telegraph, but it was not invented until fifteen years later (1837). At first there was a crowd of magnets and coils, one to represent each letter in the alphabet, then a system with five needles was adopted, and finally a single needle and code. In the needle telegraph instrument the magnet merely moves to the right hand and to the left hand, but by such means it is easy to signal the Morse Code.

The electro-magnet was invented in 1825 (by Sturgeon). Samuel B. Morse, an American artist, was shown one of these electro-magnets by a fellow-passenger while crossing the Atlantic. Morse saw at once the possibility of signalling to a distance by such means, but many years passed before he had a practical system with the well-known Morse Code.

In 1802, Humphry Davy, when working in the Royal Institution of London, discovered that when he took the wires leading from the large battery of two thousand cells, there was an electric flame produced between the ends of the wires when touched, and then separated. The heat of this flame was so great that the ends of the wires were melted. He then fixed a pencil of carbon to the end of each wire, and on separating these he found a beautiful arch or arc of light produced. This was the discovery of electric arc

lighting. It was of no practical value so long as the only source of electric current was a primary battery. Davy's discovery forms the basis also of the electric furnace.

The heating effect of a conductor through which an electric current is passing gave rise to the incandescent glow-lamp. At first a fine metal wire was tried, but better success was got by using a filament of carbon ; this was heated within a vacuum, so that there could be no combustion. In recent years the carbon filament has been replaced by fine wires of the rarer metals. Incandescent electric lighting did not come into practice until about 1880 ; it followed the invention of the dynamo.

In 1822 it was discovered that when the junction of two dissimilar metals was heated, there was a flow of electricity along a conductor joining the ends of this couple of metals. Two metals which acted well were Bismuth and Antimony. When rods of these two substances were joined together, and heat applied to the junction, there was a flow of electricity along a wire joining their free ends. The current was comparatively small, but could be enhanced by using a number of such couples to act together.

These thermo-electric currents have been used for charging accumulators, but the practical application of this discovery has been its use as a sensitive thermometer. The electric current varies with the temperature, and the thermocouple is exceedingly sensitive to heat.

In 1831, Michael Faraday made a far-reaching and historic discovery. He found that when a coil of wire is moved in the neighbourhood of a magnet, there is an electric current produced in the wire. It makes no difference whether it is the coil or the magnet which is moved.

This forms the basis of the dynamo, in which we revolve a coil of wire between the poles of a magnet, and lead out the electric current thus produced. In this we are converting mechanical energy into electrical energy.

The electric motor is merely the converse of the dynamo. If we supply mechanical motion to the dynamo by revolving its coil, we lead out an electric current from the revolving coil. On the other hand, if we supply an electric current and lead it into the stationary coil, we cause the coil to revolve. The dynamo becomes a motor, and in exchange for the electric current we get mechanical motion. The movements of the revolving coil are due to electro-magnetic action; the magnet pulls the coil round because of its surrounding magnetic field.

Faraday also discovered the electro-magnetic induction between two parallel coils of wire, through one of which an electric current is sent. He found that when a current is started in one of the coils it sets up a momentary current in a neighbouring coil, and that an enhanced effect is produced when the current is stopped, the stopping being more sudden than the starting. Nothing happens so long as the current is moving steadily.

Picture two coils of wire. In the first circuit there is a battery and a key to make and break the circuit in order to start and stop the current. In the second coil there is no source of electricity ; the circuit is merely connected to a galvanometer. On starting and stopping the electric current in the first coil we produce immediately a momentary current in the second coil. The making and breaking of the circuit may be performed automatically at a rapid rate, as in a modern induction coil. By increasing the number of turns of wire in the second or secondary coil, the pressure of the current may be increased to very high voltages.

The first attempts at wireless telegraphy were made by using the electro-magnetic induction between two parallel circuits. This system was made use of across the Sound of Mull on one occasion, when the cable broke down. Successful experiments were made over longer distances, but the disadvantage was that the length of the parallel wires had to be increased in proportion to the distance between them ; the wire used would be sufficient to connect the two places directly.

Another outcome of electro-magnetic induction is seen in the electric telephone. We speak against a disc or diaphragm which forms one side of a box containing loose carbon particles through which an electric current is passing to the line wire. The vibrations of the disc alter the electrical contact of the carbon particles and thus vary the battery current passing through them. This

varying current stimulates an electro-magnet in the distant receiver, and the pull of this magnet sets up vibrations in an iron disc or diaphragm causing it to vibrate in sympathy with the speaking diaphragm. Thus the air-waves of speech which we send against the transmitting diaphragm cause the distant receiving diaphragm to set up exactly similar waves, and in this way the speech is reproduced.

The marvel is that the little flat disc can set up the same variety of air-waves or sound-waves for the production of which we require to use our lungs, vocal chords, mouth, tongue, teeth, lips, and nose.

The valve in wireless telephony, now so popular in broadcasting, has been evolved from the incandescent glow-lamp, as related already.

Turning now to the second part of the subject, the theoretical side, it may be remarked that the only explanation which the ancients could give of the rubbed amber phenomenon was that the amber possessed a soul, and that the rubbing gave it heat and life.

Dr. Wm. Gilbert, who discovered that amber and jet were not the sole possessors of the attractive phenomenon, suggested that electricity was a fluid. Being a physician, and thinking of humours, or kinds of moisture, in the human body, he suggested that objects when rubbed emitted a fluid or effluvium, which created an atmosphere around the objects, and that this accounted for what we now call the electric field surrounding the

electrified object. This effluvium was supposed to condense and return to the object when the electric field disappeared.

A hundred years later (1729), when it was discovered that the supposed fluid could be conducted from one object to another, this idea of the returning effluvia had to be abandoned. The words of the discoverer (Stephen Gray) were that "the Electrick vertue of a glass tube may be conveyed to any other Bodies so as to give them the same property of attracting light Bodies as the glass tube does when excited by rubbing: and that this attractive vertue may be carried to bodies that are many feet distant from the tube."

The fact that Electricity could be carried from one object to another led to the idea of the electric fluid being independent of the object itself.

The idea of an electric atmosphere was abandoned later, when it was proved that the electricity resided on the surface of the object, and the idea of action at a distance was adopted in its place.

In 1733 it was suggested (Du Fay) that there were two distinct kinds of electricity. It was evident that there were at least two kinds of electrification.

About twenty years later (1750), Benjamin Franklin suggested that there was only one kind of electricity, and that the two different kinds of electrification were due to an excess and a deficit

of a single fluid. He pictured an elastic fluid. By elastic he meant that it was repulsive of its own particles. This single-fluid theory was supported by Cavendish, who introduced the notion of electric potential. It was at this time that the terms positive and negative electricities were introduced.

In 1759, in the days when men wore silk stockings, a certain philosopher (Robert Symmer) was in the habit of wearing two pairs, one above the other. On each leg he wore one black and one white stocking. On pulling off one stocking he heard a crackling sound, which he attributed to electricity, so he made some experiments. He found that the stockings of the same colour repelled one another, while a black and a white one were attracted to each other. This was really nothing new, but it appeared to him to support a two-fluid theory. It is interesting to note that Franklin, who suggested the one-fluid theory, sent some apparatus to this philosopher to enable him to test the two-fluid theory. It was thought that some of this philosopher's other experiments proved the two-fluid theory, which was afterwards generally accepted.

Later there came a reaction from these fluid theories, and it was suggested in our own time that electricity was not a thing *per se*, but merely a condition of things, such as temperature is.

This theory, that electricity was not an existing thing, but merely a condition of things—*a mode of motion*—was prevalent until the dis-

covery of electrons, which came about in the following manner.

In speaking of vacuum tubes, I have already mentioned Sir Wm. Crooke's radiant matter. He suggested that in addition to solid, liquid, and gaseous, there was a fourth condition within the vacuum tube, which he called *radiant* matter. The idea of radiant matter was not accepted. The discharge in a Crooke's tube became known as *Cathode Rays*, the discharge being from the negative electrode, which is called the cathode.

A Dutch professor (Lenard) succeeded in getting the cathode rays to escape from the vacuum tube by means of a solid aluminium window in the end of the tube, and an English professor (Schuster) made some calculations which gave proof that the cathode rays were composed of particles, but at the time the idea seemed ridiculous. Some years later it was proved that this professor was correct.

When scientists became convinced that the cathode rays were a stream of particles, the Dutch professor's experiment became of great interest. It was evident that the particles which were able to pass through a solid window of aluminium could not be particles of ordinary matter.

Sir J. J. Thomson of Cambridge made a special study of the streams of particles within vacuum tubes, and succeeded not only in proving that they were particles of negative electricity, but he was able to determine their velocity and their mass.

Hertz had tried the effect of an electric field on the cathode rays, but he got no result. It was only when Thomson used a higher vacuum that he met with success.

It was in 1897 that Sir J. J. Thomson discovered the individual electrons, and it was found that these negative electrons are identical one to another, no matter from what substance they are taken. It became evident that they are part of the constitution of matter.

CHAPTER XVIII

INTERESTING EXPERIMENTS

We have seen C. T. R. Wilson's method of making the tracks of the Alpha particles from Radium visible in a cloud. It has been found possible to make audible the movement of Alpha particles and also electrons.

When one of these very rapidly moving particles strike an atom, it usually breaks off one or more of the outer electrons, leaving the mutilated atom with a positive charge. By means of a powerful electric field, these ions increase in velocity to such an extent that their collisions produce more ions, and these produce a momentary current, or drift of electrons which, when amplified, operates a loud speaker.

We have become familiar with the Gamma rays of Radium, which we know to be X-rays of very high frequency. We know that these rays have great penetrating power—greater than rays from an X-ray bulb. We know also that those Gamma rays will ionise the air and so discharge an electroscope.

If we screen an electroscope by a massive lead block through which the rays cannot pass, and if we make a small hole through the lead block to

allow a beam of Gamma rays to pass through and fall upon the electroscope, it will be discharged very quickly. Now we can cover the hole with blocks of material, through which we wish to try and send Gamma rays. If we place a block of lead, of 1 inch thickness, in the path of the beam, we find that the rays can pass through. A 1-inch block of brass is also transparent to these rays.

Of course, the discharge of the electroscope is slower than with the open hole; it takes about twice as long to discharge.

We have seen what an important part has been played by vacuum tubes; these have been the means of discovering the electron and the proton and many other things, and also of providing us with X-rays which have helped us in connection with X-ray spectra.

It may be of interest to visualise what takes place within the vacuum tube as the air is gradually pumped out of it, the while an electric discharge is taking place within the tube. Those who visited the Royal Society Scientific Section at the Exhibition at Wembley in 1925 may remember an excellent demonstration of this being given.

The glass tube was 4 feet 6 inches in length, and was provided with electrodes. The high-voltage current necessary to produce the discharge current or stream of electrons was obtained from an induction coil and battery. The air was pumped from the tube by a rotary oil pump and a mercury pump.

Starting with the tube filled with air at ordinary atmospheric pressure, there was no discharge within the tube—the resistance of the air between the electrodes being too great, and so the electric current would rather jump across the 10-inch space between the terminals of the induction coil. The pumps, being set to work, soon reduced the air pressure within the tube sufficiently to allow a discharge, which took place in the form of lightning flashes. As the vacuum was improved, the discharge took the form of a low-pressure arc with a heating effect. This stream of electrons could be deflected by a magnet. Soon a glow of fluorescence appeared at the negative electrode, then dark spaces, known as the Faraday dark spaces, and then the Crooke's dark space, these appearing at the electrodes. The glow in the tube then breaks up into striæ like a lot of discs seen edgewise. Then the bombardment of the glass causes it to phosphoresce with a colour characteristic of the metallic element used in the making of the glass. The bombardment of the glass produces the well-known X-rays, and as the vacuum becomes more perfect under the action of the pumps, the tube becomes harder, and finally the hardness increases to such an extent that the electric discharge fails to get across the tube.

On admitting the air gradually, the same phenomena are witnessed in the reverse order.

A common laboratory experiment is to have a tube with an aluminium cross placed in the path

of the stream of electrons. The cross shelters the end of the glass from the bombardment, so that there is no phosphorescence where the shadow is. The cross may be on a hinge, so that it can be thrown down by tilting the tube. When withdrawn in this manner, the path previously in shadow phosphoresces much more brightly than the rest which has been phosphorescing all the time, and is said to have become " fatigued."

Another experiment is to have a vane arranged within the tube, so that the vane may rotate when bombarded by the stream of electrons. The direction of motion may be reversed by reversing the current, which sends the electrons in the opposite direction.

We have been picturing water waves by way of analogy for ether waves. Some interesting experiments have been arranged by Professor L. R. Wilberforce for studying the motion of waves. The waves are produced on the surface of water in a shallow trough. Little dippers are placed in the water, and these are attached to a tuning-fork, which is energised by electricity. A converging beam of light passes upwards through the bottom of the tank, and, by means of a convex lens and a mirror, an image of the surface of the water is seen on a screen. A slotted disc causes the light to pass intermittently, and this disc is coupled to a wheel, which is driven electrically by the current supplied for the fork's motion. The effect of the intermittent illumination is that the waves appear with such an apparently

slow motion that their details can be readily studied.

By using double dippers, the effects of interference of the waves may be studied. Partitions may be placed in the water in order to study the reflection of waves, and also the phenomena of shadows.

By using comb-shaped dippers, the action of the diffraction grating may be illustrated. Also a concave dipper arrangement will show the convergence of waves to a focus. By local variation of the depth of water at places, the refraction of waves, due to change of velocity, may be demonstrated.

We have considered the phenomena connected with prisms ; an interesting demonstration may be given, using a large prism and projecting the spectrum on a screen. It may be shown that the bending is different for the various wave-lengths, and it is easily observed that the longer waves (red end) are bent less than the shorter waves (violet end).

By interposing a red-coloured glass screen in the path of the red-producing waves, it will be seen that the rest of the spectrum is cut off ; the red screen allowing only the red-producing waves to pass. It is impossible to get a pure green glass ; all such glasses will let some of the red-producing waves through ; whereas, if pure, it ought to let green-producing waves pass alone.

The action of a diffraction grating may be demonstrated by crossing the prism with a coarse

grating (transparent). The lines separate the diffracted images, which are seen to depend upon the wave-length, being approximately twice as great for the red end as for the violet end.

This dependence of separation in wave-length is the basis of one method of measuring wave-lengths.

Again, by using a screen covered with zinc sulphide, and letting the invisible ultra-violet portion of the spectrum fall on it, there will be a green phosphoresence of the screen.

We have considered radiant heat, and we might take a look at that part of the spectrum.

We have seen that a thermopile is made up of couples of junctions of dissimilar metals, and that when the junction is heated, there is an electric current generated. If we place such a thermopile in the invisible infra-red rays, we see a movement of the galvanometer needle, which instrument receives the current from the thermopile; this movement indicates a change of temperature due to the heating effect of the waves below the red-producing waves. By such means the relative amounts of energy in different regions of the spectrum may be demonstrated.

We have considered the liberation of electrons under the impact of ultra-violet light, and this photo-electric effect may be demonstrated also by using visible light. It is found that the electron drift or current from a properly designed photo-electric cell is proportional to the intensity

of light over a large range, and the sensitivity of the cell is of the same order as that of the human eye. The cell is usually filled with one of the inert gases, such as Neon, and accelerating electric pressure is applied to increase the collisions between the electrons and the atomic particles (ions) of the gas, and in this way the current is magnified.

The photo-electric cell is connected to a galvanometer. When the light falls upon the cell, a current flows through the galvanometer, and this is proportional to the intensity of the light used. If a piece of wire gauze is inserted in the path of the ether waves, one half of them may be cut off, and the corresponding falling off of the electric current will be observed.

Another experiment with electrons is to shoot them into a gas and thus excite the gas to produce its spectrum. The apparatus consists of a small glass vessel (containing the gas to be examined), which is placed between the poles of an electromagnet so that the glass vessel and its contents may have a magnetic field applied to it.

Inside the glass vessel there are two filaments of platinum covered with lime ; these are parallel to one another, and may be heated by the passage of an electric current, only one being heated at a time. The purpose of these filaments is to provide the ammunition (the supply of electrons) with which the gas is to be bombarded. At a short distance between the filaments a circular piece of platinum gauze is fixed, while a circular piece of solid platinum is placed parallel to the grid at a

distance of one and a half centimetres from the gauze.

The electrons provided by the filament are accelerated or shot towards the grid by means of a difference of potential supplied by a battery to two electrodes outside the apparatus. Some of the electrons manage to pass through the space between the grid and the solid platinum disc, where they collide with gas atoms. The production of luminosity results from the recovery of the atoms after such collisions. The magnetic field is applied to concentrate the luminosity into a bright central column between the grid and the disc, and it is this column which is used in the spectroscope.

By adding a second battery so as to accelerate or retard the electrons as they travel between the grid and the disc, the luminous column may be made to exhibit marked difference of colour along its length, because of the different values of the electron energy at different distances below the grid.

We have considered *spectrum analysis,* and this refers to reading the positions of the lines in a spectrum ; we have learnt the meaning of the different lines by experience. The line spectrum of sunlight is a most complex affair, but every element has its lines in definite positions, and in this way the elements producing the lines may be recognised ; but while it is true that a particular line may always be attributed to a particular element and no other, an element may give rise to different series of lines according to the circum-

stances in which it is rendered luminous. The line spectrum of an element placed in a flame is different from that of the same element when placed in an electric arc, or, again, when made luminous by an electric discharge in a vacuum tube. In the vacuum tube a variation in the spectrum may be caused by altering the intensity of the electric discharge; the electrons vibrate at different frequencies, and, as is well known, the position of a line in the spectrum is dependent upon the frequency.

In the Bohr theory the energy for the ether waves, which produces a line, is due to an electron jumping from one orbit to another one nearer the centre of the atom. It is a fact that the molecule gives a more complex spectra than the atom. If we consider each line in the spectrum to be analogous to a wireless signal, then it means that there are many more wireless signals being sent out by the molecule than by the atom. In the spectra produced by molecules there are many fluted lines, and these are called *band spectra*, to distinguish them from the well-known line spectra of the atoms.

We have become familiar with the idea of the interference of light. In the early days of colour photography, during which we heard more of it than now, we must have heard of the Lippman process. It was invented by Professor Gabriel Lippman of Paris, and is based on the interference of light. He obtained within the thickness of the photographic film a record of colour waves in the

form of a series of extremely thin layers of silver deposit, separated by equally thin layers of clear gelatine (no deposit). When these layers are looked at in light falling upon them at a suitable angle, they show colours, just as in a soap bubble. The colour is due to the ether waves of light reflected from one layer interfering with those reflected from the next, and destroying some of the wave-lengths, leaving others to produce the resulting colours. There is, of course, no addition of colouring matter as in the other processes.

In producing his excellent photographs, Lippman prepared the plates with an extremely thin film of silver emulsion, and backed them (in the dark slide) with a film of mercury, which acted as a mirror. The light, entering the camera through the lens, passed through the transparent film of the plate, and was reflected back upon itself. At some places the one wave would assist the other wave, and thus act chemically upon the film, whereas at other places the one wave would be in opposition to the other—a crest being superimposed upon a trough, and at such nodes there would be no photographic action. The result was that there was produced in the film light and dark layers, separated by distances proportional to their wave-length.

For example, red-producing waves would affect layers farther apart than those corresponding to the violet end of the spectrum. The layers may be distinguished by means of a microscope.

We have considered the marvellous con-

struction of matter, and surely no one can think that this has come about by chance. When Kepler had been examining the celestial universe, and the appearance of a new star, he was surprised that the Epicureans put forward the suggestion that the star had come about by a fortuitous concourse of atoms, and he said :

" I will tell those disputants, not my own opinion, but my wife's. Yesterday, when weary with writing, and my mind quite dusty with considering these atoms, I was called to supper, and a salad I had asked for was set before me. 'It seems then,' said I aloud, 'that if pewter dishes, leaves of lettuce, grains of salt, drops of water, vinegar and oil, and slices of egg had been flying about in the air from all eternity, it might at last happen by chance that there would come a salad.' 'Yes,' says my wife, 'but not so nice and well dressed a salad as mine.' "

CHAPTER XIX

CONCLUSION

It is a long step from the elements earth, air, water and fire to the ninety odd elements of to-day, all of which we know to be composed of electricity.

Dr. Adam Smith, F.R.S., writing in 1795, said :

" From arranging and methodising the system of the Heavens, philosophy descended to the consideration of the inferior parts of Nature, of the earth and the bodies which immediately surround it. . . . To render the lower part of the great theatre of Nature a coherent spectacle to the imagination, it became necessary to suppose that all the strange objects of which it consisted were made up of a few with which the mind was extremely familiar. . . Of all the bodies of which the interior parts of the universe seem to be composed, those with which we are most familiar are the earth, which we tread upon ; the water, which we every day use ; the air, which we constantly breathe ; and the fire, whose benign influence is not only required for preparing the human necessities of life, but for the continual support of that vital principle which actuates both plants and animals. These, therefore, were supposed to be the elements. . . . The heat, observed in both plants and animals, seemed to demonstrate that fire made a part of their com-

position. Air was not less necessary for the subsistence of both, and seemed, too, to enter into the fibre of the animals by respiration, and into the plants by some other means. The juices which circulate through them showed how much of their texture was owing to water. And their resolution into earth by putrefication discovered that this element had not been left out in their original formation."

It was just shortly before this that the modern view of the chemical elements was introduced by Lavoisier (1789). He said:

". . . Every substance which we have not been able to decompose is for us an element, not that we can be certain that bodies which we regard as simple are not themselves composed of two or even a larger number of elements, but because these elements can never be separated, they act as elements."

The would-be scientist requires to be the possessor of powers of imagination, as he has to deal with things far, far below the range of vision. In the present volume we have been considering infinitesimally small things, such as molecules, atoms, electrons and protons, and it is quite hopeless to visualise the actual size of even the largest of these—the molecule.

Sir John Leslie of Edinburgh tried to determine the number of molecules in a grain of musk.

A single grain of musk could continue to scent the often renewed air of a room for twenty years, and yet all the time it must be giving off particles which enter the nose and stimulate the sensation

of smell. The conclusion at which he arrived was that the grain of musk must contain at least 320,000,000,000,000,000,000,000,000 (320 quadrillions) of molecules.

It is interesting to inquire how many molecules there would be in a row measuring 1 inch. The answer is 500 million molecules. A row of the same number of dried peas would extend to 2250 miles — an enormous difference between 2000 miles and 1 inch.

Dr. Aston of Cambridge has drawn another mental picture to help us to realise the multitude of molecules contained in a small quantity of matter. He says :

> " Take a tumbler of water, and—supposing it possible—label all the molecules in it. Throw the water into the sea, or indeed anywhere you please, and after a period of time so great that all the water on the earth, in the seas, lakes, rivers and clouds, has had time to become perfectly mixed, fill your tumbler at the nearest tap. How many of the labelled molecules are to be expected in it ? The answer is roughly two thousand."

In other words, there are two thousand times more molecules in a tumbler of water than there are tumblerfuls of water in all the seas, lakes, rivers and clouds. And yet the molecule is large compared with the atoms of which it is composed, while these atoms are giants compared with the electrons.

Sir Oliver Lodge has said that if the atom were magnified to the size of a church or large hall, the

electrons in its composition would appear about the size of grains of dust. They occupy the space of the atom by virtue of their movement.

Even the electron is large compared with the proton or positive particle.

Is it not remarkable that we can experiment with such infinitesimally small things as electrons and protons? I have heard it said that the scientist has to take these particles on faith, but we have positive proof of the existence of even the electrons and protons.

In our imagination we can follow the creation of the physical universe commencing with the ether, but we fail to discover the method used by the Creator in forming the particles of electricity of which the material universe is composed.

Sir Oliver Lodge has suggested that radiation may be creating matter in the confines of space, and it is interesting in this connection to read in the first chapter of Genesis that, at the very outset of creation, the Creator said, "Let there be Light." It is interesting to find in this beautiful poetic description the idea of radiation preceding the creation of matter.

We have seen that all atoms are not eternal, and we may doubt if any of them are; but there is a suggestion that there may be a cycle—matter becoming radiation, and radiation becoming matter.

We have become familiar with the idea of electricity being atomic, and in this connection it is interesting to note what Benjamin Franklin wrote in 1750:

Conclusion

" The electrical matter consists of particles extremely subtle, since it can permeate ordinary matter, even the densest, with such freedom and ease as not to receive any appreciable resistance."

This declaration was made by Franklin in the days when electricity was only known in electrified bodies, and fifty years before the discovery of the electric current.

It was in 1881 that G. Johnstone Stoney stated the numerical value of the particle of electricity which was not discovered in the laboratory till 1897, and which was spoken of by its discoverer, Sir J. J. Thomson, as a *corpuscle.* It was Johnstone Stoney who christened it the *electron.*

We have pictured the atoms separated from one another by space filled with the ether, and even these atoms are by no means solid, for we have seen that they are made up of electrons and protons, forming an open solar system. The real mass of all matter resides in these infinitesimally small protons. It has been said that if the whole of the protons existing in the Earth could be placed together—with no space between them—they could be contained in a hand-bag—but needless to say, the handbag could not be carried by the greatest giant that ever lived, for its weight would be six thousand trillion tons, which is the weight of the Earth, and which, stated in figures, looks colossal. Here it is: 6,000,000,000,000,000,000,000 tons. This gives us some idea of how porous all matter really is.

Conclusion

Reference has been made to disintegration of elements by bombarding them with Alpha particles (Helium atoms) shot off by exploding Radium atoms. Nitrogen was the first atom to be damaged successfully, since when there have been added atoms of boron, fluorine, sodium, aluminium, phosphorus, neon, magnesium, silicon, sulphur, chlorine, argon and potassium, all of which have been disintegrated.

Indeed, all the elements from boron to potassium have been disintegrated, with only two exceptions—oxygen and carbon.

We have considered the atomic number as the numerical place of the elements in the Periodic Table, arranged according to the number of positive charges in the nucleus, and we have seen that this came about through Moseley's work with X-rays forming spectra, showing how each step from one element to the next in the Periodic Table showed the addition of one unit of positive charge.

In closing, it should be pointed out that the subjects considered in the present volume cover such a wide field that a great deal of interesting detail has had to be omitted, but it is hoped that many readers will follow the subject further on their own account.

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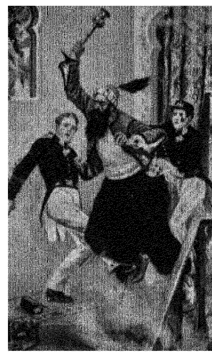

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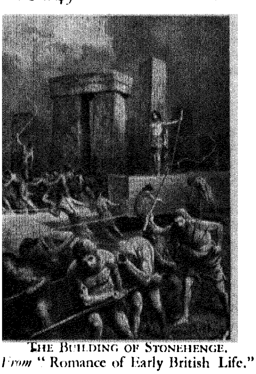

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